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SOME IMPORTANT REGULAR PATTERNS IN TECTONIC STRUCTURE AND CRUSTAL MOVEMENTS[1]

by

G. D. AZHGIREY

Regional faults and folded linear zones of de- mation in the earth's crust, along with their ietic features, distribution, and geologic ucture, have long been a subject of numerous estigations, especially after the publication E. Suess' world survey [31]. In Russia, in- est in linear zones of deformation was stim- ited by A. P. Karpinskiy [4]; outstanding iong foreign works are those by W. Seidlitz 5], A. Sieberg [26], and R. Sonder [28, 29]. e arcuate form of folded formations was noted W. Hobbs [22], R. Staub [30], W. Bucher 7, 18], H. Hess [20], J. Wilson [34] and B. Rukhin (Paleogeografiya, 1959).

Li Sy-Huan [10] and S. Tokuda [32] appar- tly were the first to study the kinematics of ctonic movements in oceanic island arcs and some extent, in folded arcs.

After the discovery of deep-seated earth- iakes by seismologists, the geologic signifi- ince of these important structural elements of e earth has been discussed by A. N. Zavarit- kiy [3] and N. S. Shatskiy [15].

A. V. Peyve [12] introduced the concept of eep rifts, their structure and development, as ow accepted by many geologists.

In this paper, the author proposes to reinter- ret the significance of many facts pertaining to ie morphology, structural position, and geo- ogic development of major linear tectonic zones.

FOLD BELTS AND THEIR RELATION TO DEEP-SEATED STRUCTURES

N. S. Shatskiy and A. N. Zavaritskiy have lemonstrated in the works mentioned above that old belts, at least those in present oceanic is- and arcs, represent exposures of world-wide zones of great tectonic activity. These zones, udging from the deep earthquakes originating in them, descend far below the crust and into the mantle. Inasmuch as the structures of present oceanic island arcs quite definitely continue within the continents, e. g., the Indonesian fold arcs traceable without interruption into folded mountains of Burma, China, and India (Figure 1), there are reasons to believe that deformation within intracontinental fold belts is dynamically and kinematically similar to that of the island arcs, on the whole.

A possible objection to such a conclusion may by that geologic conditions of formation of structures in intracontinental belts are different in some way from those prevailing at the boundary between continental and oceanic segments of the crust, where many island arcs are located. There are reasons to believe, however, that these differences are of secondary importance in the mechanism of tectonic deformation. The thickness of the crust is generally small as compared to the depth of world-wide zones of earthquake distribution; therefore, the difference in thickness between continental and oceanic crusts is not especially important. As to physiomechanical properties of crust-forming rocks, W. Bucher [17] has demonstrated that continental and oceanic crusts behave in the same way in major tectonic deformations.

These concepts appear to find confirmation in the southeast Asian island arcs recently described by H. Hess [21] and R. Dietz [19] and forming a triple garland system, progressively farther away from the continent: 1) the Ryukyu — Taiwan — Philippine Island garland; 2) the Parcel — Vella garland (the Palau-Kyusyu anticline of H. Hess [21]); the 3) the Marainnas — Bonin Islands garland (Figure 1). Strictly speaking, garlands one and two are no longer a boundary between continental and oceanic segments of the crust; this boundary is also marked by the andesite line passing along the outer Mariannas — Bonin garland.

Another objection is that zones of deep earthquakes are present only in a zone separating the oceans and continents, rather than everywhere. However, the wide distribution of earthquakes deeper than 300 km, below the south Tyan'-Shan'

[1] O nekotorykh vazhnykh zakonomernostyakh tektonicheskogo stroyeniya i dvizheniy zemnoy kory.

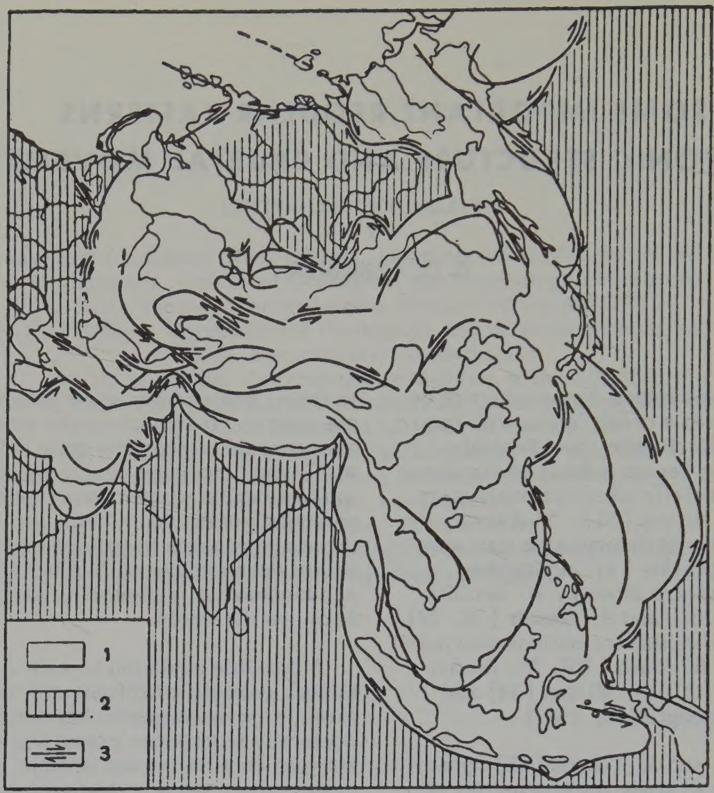

FIGURE 1. Garlands of arcs of deep faults and fold formations of Asia.

1 - mobile belts; 2 - ancient platforms and oceanic troughs; 3 - arcs of deep faults and fold systems. Arrows indicate the direction of lateral displacement for those places only where it is well defined by an echelon structures.

and the Pamirs fold structures [1, 13], makes it possible to project zones of deep earthquakes into the interior of continents.

Folding, as a merely surficial phenomenon affecting a thin layer of rocks which form the crust, cannot be the leading factor in forming structures which determine the main features of deformation in world-wide belts and deep-seated zones of higher activity. Old concepts of crustal deformation between platform massifs, where the main significance was attached to fold structures as an expression of the principal process of deformation are slated for oblivion.

The zones of intensified activity, passing into the mantle, should be called, along with their surficial fold structures, zones of deep faults, because such deep faults are a characteristic structural feature of the zones of higher activity; they originate there long before the folding, as early as the initial stages of the geosynclinal phase in the development of a mobile belt, and persist for a long time, more or less uninterruptedly.

The surficial fold belts, too, would be more properly called deep fault belts, or even more precisely, as has been done for a long time, mobile belts.

The necessity of admitting a genetic relationship between the so-called geosynclinal-type folding and the principal radial structures of the earth does not mean that the formation of geosynclinal folds must be associated with the effect of radial tectonic forces. That topic is not discussed in this paper. However, numerous data have been brought up before, clearly demonstrating the formation of geosynclinal folding in conjunction with obvious lateral compression. We believe that it is during these epochs of tangential stresses in the mantle and crust that matter rises in thermal currents along the deep fault zones; and it is then that fold structures are formed.

his concept of deep fault zones is being ad- ed against the hallowed idea of deep faults g individual structural sutures or independ- zones of crushing. As the matter of fact, faults are nothing but narrow (sutural) to paratively broad bands of concentrated de- nation which develop wholly within a zone of nsified tectonic activity, embracing the h of each mobile belt. Within such a belt, rmation may be concentrated along a single t, but mostly within a system of parallel or commonly plumate faults. Elsewhere, concentration takes place along joints and l shearing planes.

This, each individual suture and band of a p rift is the manifestation of a resolution of rents of matter in the process of deforma- ; a true, scientifically substantiated analysis his deformation is possible only when it is lied to the entire mobile belt as a whole ner than to an individual structure within e deep fault zone.

First order folds are developed in this belt a secondary formation which comlicates the ustal segments previously weakened along lier faults and shear zones, as has been well ablished by detailed mapping and a study of genesis of individual major folds in north ucasus. It is justifiable, therefore, to re- d mobile belts, including their associated d structures, as an expression of world-wide nes of weakness in the uppermost solid shell the earth, its crust [6].

IMPORTANT REGULARITIES IN THE DEFORMATION OF MOBILE BELTS

We use the above considerations as a basis r our attempt to discover regularities in the formation of mobile belts. In this connection, emphasize the arcuate arrangement of fold ructures in mobile belts (Figure 1). Although me of them may have been due to different uses, most of them are directly related to the cuate plan of deep faults which control the rangement and form of the fold structure in obile belts and which display elements of teral displacement. This premise does not eclude the existence of rectilinear regional ults possessing the characteristic of deep ults. The object of further study is to deter- ine their relationship to the arcuate zones of eep faults.

An analysis of very extensive factual material be published subsequently shows that an im- ortant regularity in the kinematics of deforma- on developed in a mobile belt arc is a left ateral displacement in the left limb of the arc, s viewed from inside, and a right lateral shift the right limb (Figures 1 and 2). Exception this rule are very rare and almost always ave a rational explanation.

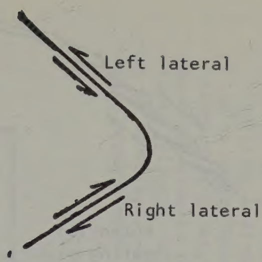

FIGURE 2. Basic diagram of a regular lateral displacement along the deep fault controlling a folded arc

The more profound reasons for such a regularity in the deformation kinematics for a nascent arc are beyond the scope of this paper. The fact of this regularity is important. To be sure, a possible mechanism and the dynamic conditions of the arc formation will have to be considered in the future, in cooperation with geophysicists.

A proof of our main thesis is the en echelon arrangement of a system of folds, on one hand, and the arrangement of diagonal shifts in plumate faults, widely developed in mobile belts, on the other (Figure 3).

The question immediately arises of the magnitude of lateral shifts which bring about the en echelon arrangement of tectonic structures in a mobile belt. According to all data, such shifts are not large for individual rifts, usually being measured in kilometers and tens of kilometers. Diaplacements approaching one hundred kilometers are postulated by Ye. A. Kuznetsov and Ye. Ye. Zakharov [7, 8] for the Degtyarsk fault, and by L. B. Vongaz for the Fergana fault [2]; such figures are, however, exceptional. For a folded arc, on the other hand, total lateral displacements in its limb, along parallel faults and shear zones appear to reach many tens of filometers frequently.

Abroad, recent works of J. Moody and M. Hill [24], L. Sitter [27], P. Amand [16], and many others, stress the broad development of lateral faults. However, their analysis of dynamic conditions responsible for such movement is usually confined to a consideration of the resolution of specific tectonic forces and does not give an idea of the relationship of stresses responsible for such displacements to the entire complex of orogenic forces.

AN EXAMPLE OF ANALYSIS OF THE DEFORMATION IN A MOBILE BELT FROM CAUCASIAN DATA

The Crimea and the Greater Caucasus, from Taman Peninsula to Shakh-Dag, which form a

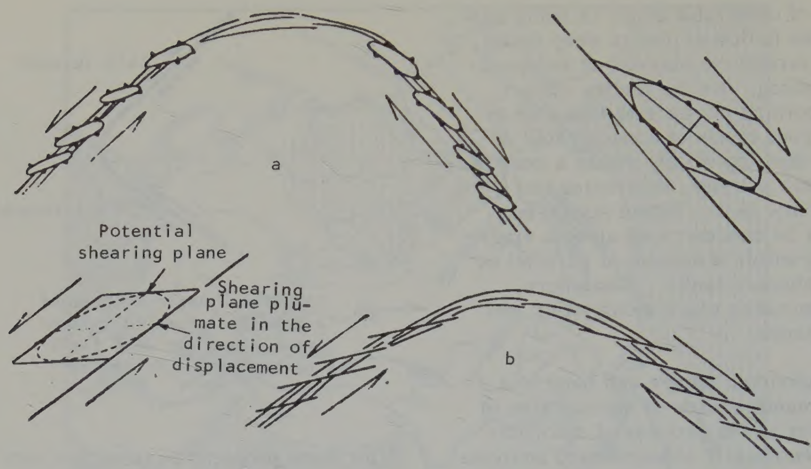

FIGURE 3. En echelon arrangement.

a - of anticlinal folds; b - of faults developing from plumate shearing planes

folded arc convex toward the Russian platform (Figure 4)are cited as an example.

The relationship between the geologic history and development of the Crimean and the Greater Caucasian limbs of the arc is unquestionable [11]; in recent years it has found a new confirmation in V. I. Slavin' discovery [14] of a Triassic shale facies similar to the Crimean Taurian formation, in the Mzymta area. The earlier controversy on the nature of the junction between the Caucasus-Taman fold structures and those of Kerch Peninsula, does not invalidate this conclusion, in our opinion, because it pertains to more specific phenomena.

Tectonic movements which have formed the Crimean and Caucasian arcs, as we know them, were initiated in Jurassic time, continued during the Cretaceous and Paleogene, and reached their highest intensity in Neogene time.

In addition, the Greater Caucasus structure exhibits a well-defined element of the first order of magnitude, the so-called Tyrnyauz-Pshekish suture structure of an earlier origin: early Paleozoic or older. This major tectonic suture represents a sector of an ancient folded arc; it underwent a slight rejuvenation in the Mesozoic and Cenozoic, and that only in those segments favorable oriented in relation to a deep fault of the Alpine fold structure in the Crimea and Greater Caucasus. A description of the Tyrna-Auz sutural structure is found in a paper by D. S. Kizeval'ter [5]. Recently O. V. Kononov has uncovered definite evidence of left lateral displacements in the Tyrny-Auz area (personal communication). These lateral shifts appear to be recent, of Alpine age. S. M. Kropachev and A. M. Demin, studying the Tyrny-Auz structure in the Teberda basin, somewhat to the west, have determined independently that Paleozoic folds and faults are cut at a sharp angle in a wide belt north and south of the Tyrnyauz-Pshekish suture, which suggests ancient left lateral movements along it (personal communication).

The arc of Mesozoic and Cenozoic peripheral folds of Dagestan, likewise convex toward the Russian platform, is controlled by a deep structure which may date back to the Paleozoic, judging from its probable junction with the Tyrnauz suture structure, by way of minor arcs of the Terek-Sunzha fold system. In the Alpine stage, deep faults of the northern arcs were merely rejuvenated and were characterized by weakened secondary movements.

The main Mesozoic-Cenozoic deep fault, which determines the configuration of the Alpine folded arc of the Caucasus and Crimea, passes through the Greater Caucasian highlands. It has no physical expression as a rule; it is a comparatively broad (10 to 20 km) belt with evidence of intensive tectonic crushing and a regional metamorphism of greenstone dike rocks, Jurassic and younger, and with Jurassic differentiated intrusions of gabbroid magma, as well as assorted granitoid neo-intrusions ranging from Jurassic to Pliocene in age.

The entire complex of these tectonic, metamorphic, and igneous phenomena, despite the vagueness of the boundaries of localization of each individual unit, allows a definite plotting of the deep fault zone, thus rendering quite unfounded the scepticism of some geologists as to an actual proof of the existence of most deep faults. It does not necessarily follow that main deep faults should be expressed in definite sutures, although such examples are not

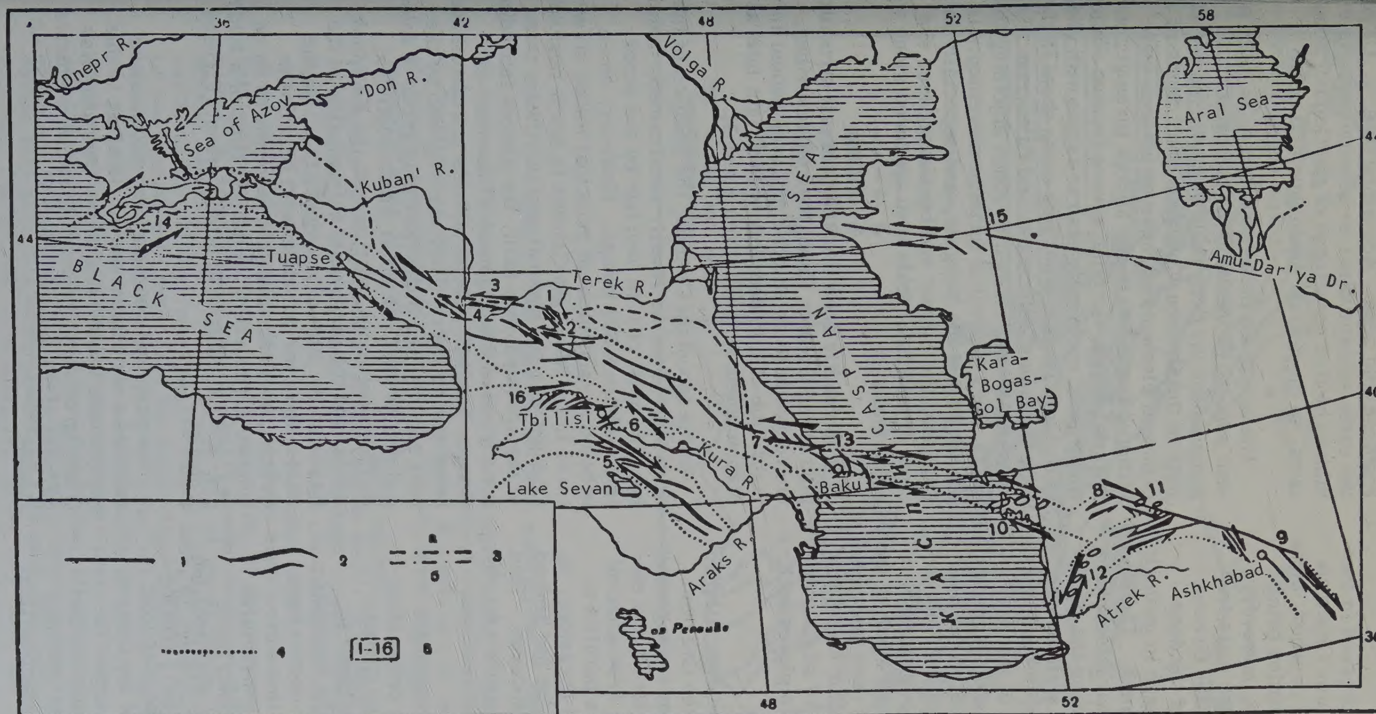

FIGURE 4. Scheme of lateral displacements in deep fault zones in mountains of the southern part of the U.S.S.R.

1 - Major Mesozoic and Cenozoic faults with lateral displacement; 2 - some major anticlinal structures of the same age, forming en echelon system; 3 - Paleozoic deep faults: a) traced; b) assumed; 4 - boundaries of tectonic belts and segments adjacent to lateral faults; 5 - references to descriptions of en echelon structures and lateral faults: 1) Kusparity, after G.M. Yefremov, 1937; 2) Holst, after G.V. Khetagurov, 1958; 3) Tyrny-Auz, after O.V. Kononov, 1958; 4) Kti-Teberda, after R.Yu. Orlov, 1957; 5) Somkhit zone, after L.N. Leont'yev, 1949; 6) Gombor structures, after A.V. Ul'yanov, 1930; 7) Beshmardak cordillera, after a map of A.S. Azerb S.S.R., 1958; 8) lateral faults in west Kapet-Dag, after G.I. Klyayev, 1945; 9) lateral faults in southeast Kopet-Dag, after P.I. Kalugin, 1945; 10) en echelon folds in Cheleken, Kotur-Tepe, Nebitdag, after Yu.N. Godin, 1959; 11) en echelon folds along the main Ashkhabad fault, after Yu.N. Godin, 1949; 12) en echelon folds in the southwestern territory, after P.I. Kalugin and M.P. Sukacheva, 1954; 13) en echelon folds of Apsheron Peninsula, after I.I. Potapov, 1958; 14) en echelon folds of the Taun and Faros uplifts, after M.V. Muratov, 1949; 15) en echelon structures of Mangyshlak, after A.L. Yashin, 1959; 16) en echelon structures of Adzhar-Trialet mountains, after D.A. Buleyshvili, 1958.

uncommon (the Tyrnyauz suture; the Irtysh zone of crushing; sutures of the main structural line of Tyan'-Shan', within Kara-Tau, and the San Andreas fault in California; the Alpine fault in New Zealand, etc.).

More often deep faults are expressed in the same way as they are in the Greater Caucasus Mesozoic deep fault: as a band of crushed, metamorphosed rocks with the deformation being localized in a narrow zone. This, however, does not render less convincing the main features of a deep fault. Indeed, in the Greater Caucasus, both north and south of the deep fault zone, there is a radical change in geologic structure and pattern of development. The tectonic block to the north of it is characterized by its relatively uplifted position during the Jurassic, Cretaceous, and Paleogene, with the corresponding expression of this fact in the lithology, thickness, and constitution of its sedimentary section. On the other hand, segments of the south tectonic block, nearest to the fault zone, have been marked by a comparatively depressed position, ever since the beginning of Mesozoic sedimentation. Deposited south of the central Caucasian segment of the deep fault zone were shales and silts of the Tsiklaur formation, accompanied by submarine flows of slightly differentiated porphysitic diabase, in places spilitic magmas.

A very important feature of the over-all plan of regional tectonic structure in the Greater Caucasus is the definite en echelon arrangement of major Mesozoic and Cenozoic structural elements. This phenomenon, in the area adjacent to the Main Range and high ranges parallel to it, has been described on various occasions, in connection with different topics, and for limited areas, by many students of the Caucasus. This is the first generalization from this data for the entire fold system of the Greater Caucasus.

As it turns out, the overwhelmingly predominant trend of almost all first order Mesozoic and Cenozoic structures in the Greater Caucasus is the sublatitudinal northwest to west-northwest general trend of the Mesozoic-Cenozoic deep fault zone. On the north slope, to the west, away from that zone in a sublatitudinal direction, the following structures branch off consecutively and die down in the east: the Peredovoy (Front) Range anticlinorium; the synclinorium of a segment of the Tyrnyauz-Pshekish suture, rejuvenated in the Mesozoic and Cenozoic; the anticlinorium of the Central, Main, and lateral Balkar-Digor Ranges; the Shtulu-Kharess trough synclinorium; the Dar'yal-Bogos Main Range; the Bezhitin synclinorium; the Kakhetinsk Main Range anticlinorium; etc. (Figure 5).

On the south slope, to the west, away from the Mesozoic-Cenozoic deep fault, the following structures branch off consecutively in a sublatitudinal direction, and die down in the west; the Akhtsu-Katsirkhi cordillera; the Abkhazian fold zone; the Kelasur cordillera; the Kodor-Svanetian fold zone with the Svanetian Range cordillera; the Korty cordillera; and the Pachinsk fold zone. According to A. V. Ul'yanov the same sublatitudinal en echelon trend is exhibited by fold structures of the Gombor Mountains, in the Shirak-Adzhinaur fold zone.

The age of all these structures, in their present aspect, is Mesozoic or Cenozoic, i. e., the same as for the deep fault which forms the right limb of the Crimea-Caucasus arc. Some of the principal elements of these structures were initiated in the Early and Middle Jurassic, as regional faults; the others were formed somewhat later, apparently also as faults with chains of tectonic islands emerging along them in the Late Jurassic Cretaceous, and Paleogene. Fold structures were formed in zones adjoining the faults. In a revival of tectonic movements in the second half of the Neogene, and especially in the Pliocene, the largest and best expressed systems of anticlinal folds also appeared along the same faults.

It is readily seen that the over-all structural plan of the Greater Caucasus, as described, corresponds to an en echelon arrangement in the right limb of a folded arc, to the right lateral displacement type (Figures 2 and 3).

In the Mountain Crimea, the position of the deep fault is not as readily ascertained, mainly because most of it is overlain by the superimposed Black Sea trough. However, an en echelon arrangement of principal folded structures in the Mountain Crimea is fairly obvious. Coupled with the general east-northeast trend of the assumed deep fault, the almost latitudinal structures of the Taganash-Dzhorzhav and Chegen-Yenikali groups of folds are distributed from east to west. They are followed by the next echelon, the Sudak-Karadag group of folds and that of the Tuak uplift which continues farther west to its junction with the Kachinsk uplift, and the more southerly echelon of the Faros uplift, now submerged [11]. On the whole, the over-all structural plan of the Crimea, as described, corresponds to an en echelon arrangement in the left limb of a folded arc, with a left lateral displacement (Figures 2 and 3).

The practical consequences of the above analysis are of importance. The fact is that the tectonic subdivision of the Caucasus was done, up to very recently, based on segments parallel to the general trend of this mountain system.

As a first approximation, such a subdivision into tectonic segments had a positive value. However, in detailed metallogenic studies of large-scale maps, the en echelon arrangement

FIGURE 5. A scheme of tectonic subdivision of the Caucasus

1 - zone of Paleozoic deep faults, 2 - Mesozoic-Cenozoic deep fault of the Greater Caucasus; 3 - north boundary fault of the Adzhar-Trialet fold zone; 4 - other major faults; 5 - outlines of the Rion and Kura troughs; 6 - outcrops of upper Paleozoic marine deposits; 7 - Hercinian granitoids; 8 - Flysch spurs (Cretaceous-Paleogene); 9 - superimposed troughs (Pliocene-Quaternary).

Tectonic regions:

I - Donbas synclynorium and the Don-Caspian swell; II - Azov-Podol shelf; III - platform segment of the Azov-Kuban' and Terek-Kuma troughs (Scythian Platform); III-a - West Cis-Caucasian syneclise; III-b - East Cis-Caucasian syneclise; III-c - Stavropol' uplift; IV - foredeeps of the Greater Caucasus meganticlinorium; IV-a - West Kuban foredeep; IV-b - East Kuban' foredeep; 1) South Stavropol' complex anticline; IV-c - Terek-Caspian foredeep; 2) Terek complex anticline; 3) Malo-Kabardinsk and Sunzha complex anticlines; 4) Kabardinsk trough; 5) Osetin trough; 6) Kusaro-Divichino trough; V - the Greater Caucasus meganticlinorium; 7) zone of the Peredovoy (Front) Range and north meganticlinorium; 8) Tyrnyauz-Pshekish suture zone; 9) the western Main Range Zone; 10) zone of the Central Main Range (and the Balkar-Digor Bokovoy (Lateral) Range with a northern monocline; 11) Shtulu-Kheres synclinal zone; 12) zone of Dar'yal-Bogos Main Range (Bokovoy Range of Daghestan with the north monocline); 13) outer Dar'yal folded shelf with the northern monocline; 14) Bezhitinsk synclinal zone; 15) the Kakhetinsk Main Range zone; 16) the Dagestan-Azerbaydzhan Main Range zone; 17) main deep fault of Alpine Greater Caucasus. Flysch troughs: 18) west; 19) east. South folded fringe of flysch troughs: 20) Abkhaz fold zone; 21) Kordor-Svanetian fold zone; 22) Rachinsk fold zone; 23) Shirak-Adzhinaur (Kakhetinsk) fold zone; 24) Vandam fold zone; 25) Adzhichay-Alyat fold zone; 26) Alazan-Bidrymanchay superimposed zone; VI - intermontane basins and saddles; 27) Rion trough; 28) Denrul massif; 29) Mukhran-Tfan trough; 30) Kura trough; VII - Little Caucasus meganticlinorium; 31) Samkhet-Karabakh anticlinorium; 32) Sevan synclinorium; 33) Miskhan-Zangezur anticlinorium; 24) Yerevan'-Ordubad synclinorium; 35) Araks anticlinorium; VIII - meganticlinorium of the Adzhar-Trialet fold province.

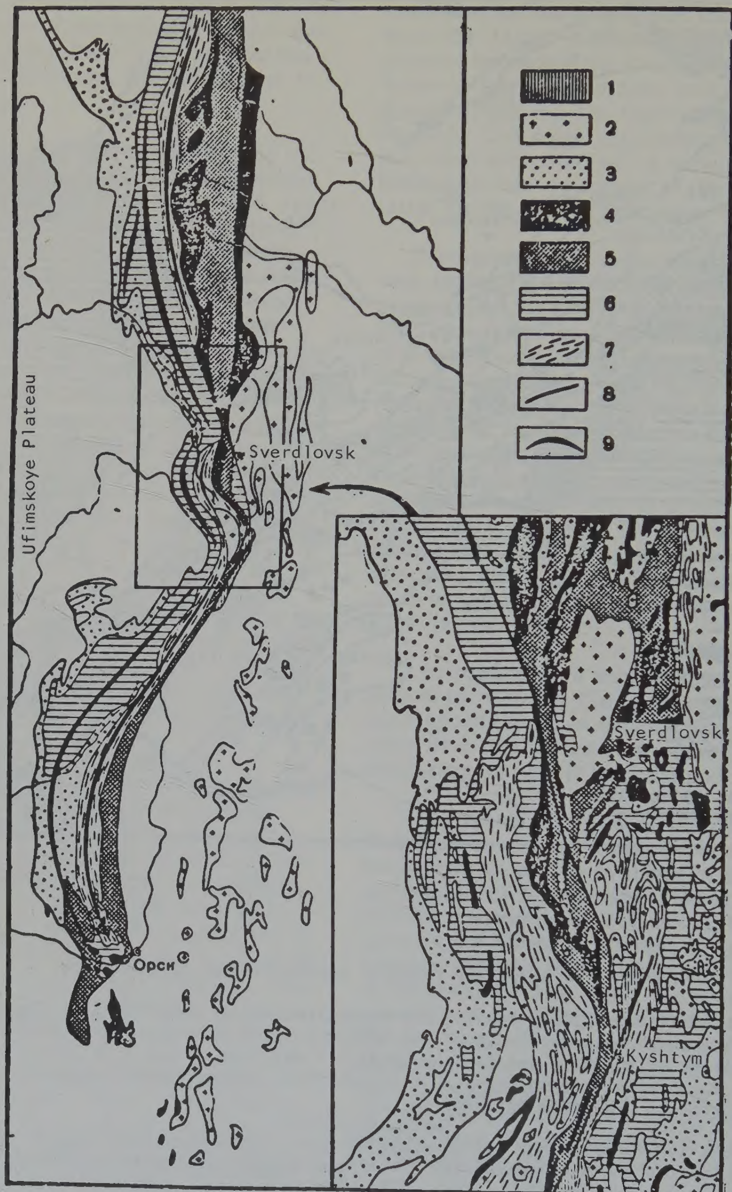

FIGURE 6. Arcuate fold complexes and lateral faults of the south and middle Urals. Compiled from data of Ye.A. Kuznetsov and the 1:2,500,000 geologic map of the U.S.S.R.

1 - Hercinian alkalic intrusions; 2 - Hercinian and older granite intrusions; 3 - Carboniferous and Devonian deposits of the western slope; 4 - post-Caledonian basic intrusions, Hercinian in the south; 5 - Ordovician and Silurian rocks of the greenstone zone; 6 - Lower Paleozoic and Silurian rocks of the western slopel 7 - metamorphic rocks, chiefly crystalline schists; 8 - lateral faults; 9 - axes of folded arcuate structures.

ndividual structural elements of the Caucasus ame so obvious that it had to be taken into sideration for specific forecasting.

A similar regional structural analysis has n carried out for Hercinian folded arcs in south and middle Urals (Figure 6), from the a of Ye. A. Kuznetsov and Ye. Ye. Zakharov 8], and for west Tyan'-Shan' from our own published data; for late Alpine arcs of Kopet- (Figure 4); for Laramie arcs of the Rocky untains, U. S.; the Coast Ranges of Canada; many other regions. Similar regularities e been described for fold structures of the st Indies (Figure 7), and oceanic island arcs Ryukyu, Indonesia, and the Philippines (Fig- 1). It has been observed in these areas t an arc, formed at the surface by fold struc- es of a definite age and corresponding to a ep fault arc, exhibits along with other fea- es a definite left lateral displacement in its t limb and a right lateral displacement in its ht limb.

same token, it is necessary to look into the corollaries of this hypothesis. Because of the limited amount of space, the following exposition is given in he form of an abstract. In the future, the author proposes to consider these points in more detail.

1) Unity in the deformation kinematics of oceanic and continental arcs. The similarity in regularities of the orientation of en echelon systems of folds in present oceanic island arcs and other features in the development of oceanic and intracontinental arcs of mobile belts gives reasons supplementary to those stated above, for assuming the same dynamics and kinematics of tectonic movements for all such arcs.

2) Deep-seated faults, long-developed and newly formed. Deep faults, which are among the most important structure-determining elements of mobile arcs, have maintained their activity during the entire history of the earth, in some instances, thereby predetermining the

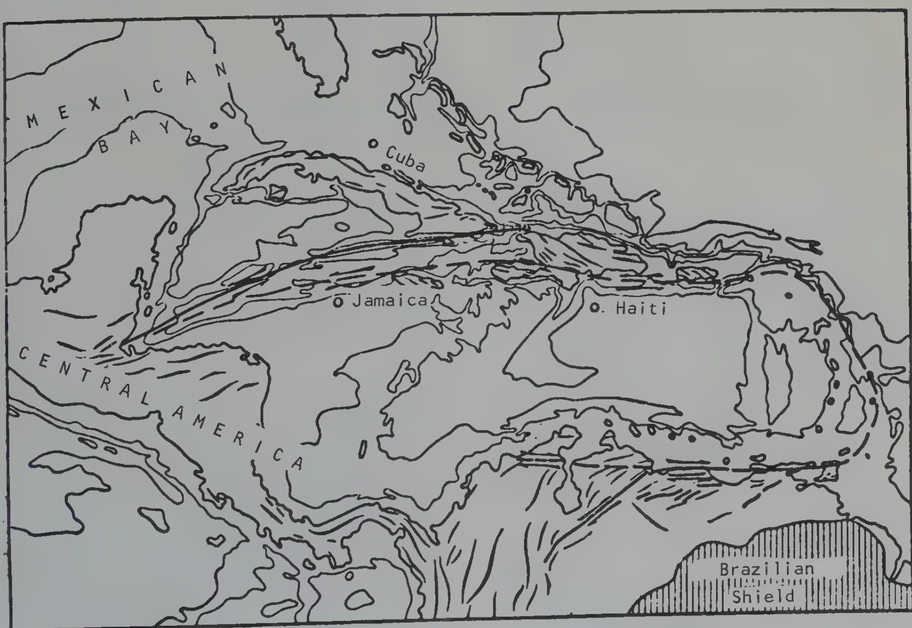

FIGURE 7. A loop formed by lateral faults and en echelon fold structures of the West Indies.

Compiled after W. Bucher, H. Hess, J. Moody and M. Hill, and others.

SOME GENERAL CONCLUSIONS

On the basis of the above analysis, we believe t possible to advance, as a working hypothesis subject to further verification and development, a concept of the world-wide validity of these regularities in the kinematics of tectonic deformation in the arcs of mobile belts. By the

importance of inherited tectonic trends, structures, and channels for the passage of metamorphosing fluids, magmas, and ore-bearing emanations. In other instances, there is a quite definite lowering of activity and even the cessation of activity of old deep faults and the birth of new ones within mobile belts, e. g., the lowering of activity in the Paleozoic

Tyrnyauz-Pshekish suture and the development of a Mesozoic deep fault zone of the Greater Caucasus Main Range. This extremely important point emphasizes once more the fallacy of traditional views on the significance of isolated deep faults observed in surficial zones of the earth's crust.

Elsewhere, as in the western cordillera of North America at the beginning of the Tertiary, deep fault zones are formed anew in platform segments adjacent to mobile belts. In that way, such platform segments become involved to a variable extent in a mobile belt.

3. A more strict definition of the term, deep-seated fault. It is possible that, in the light of the above exposition, the term "deep-seated fault" should be further defined. Among the many major deep-seated fractures in geosynclinal provinces, I propose to consider those first order faults which are axial features of major fold structures united into definite arcs. Well-defined differences in sedimentary conditions and other physiogeographic and geologic features have been observed in tectonic blocks separated by such faults. This has been generally accepted as the main criterion of a deep fault, suggesting its relation to deeper reaches of the earth and its extremely long life span [12].

However, substantial differences in geologic structure have also been observed in connection with considerably smaller faults, roughly parallel to the deep fault or else plumate ot it. It may be that such faults of second and higher orders should not be called deep faults at all, because of the difficulty of drawing a boundary between them and local faults. Indeed, many of the latter had a long period of formation, in connection with that of the first order deep fault with which they are genetically associated. Under this definition, the most important criteria of a true deep rift will be augmented by the notion of lateral displacement, - right lateral for the right limb of the arc, and left lateral for its left limb.

4) Individualization of arcuate structures. An analysis of tectonic structures in deep fault zones and the associated arcs of folding leads to the conclusion that each such arc is linked to the next one not by means of a reverse arc, as a rule, but is joined with it, or even intersects it, at a large angle, commonly close to a right angle. This remarkable feature allows identification of individual arcs. In addition, it often happens that a garland of arcs exhibits geologic features of different ages; it happens occasionally that structures of younger arcs definitely cross those of the older.

Apical segments of the arcs are usually marked by a depressed level of contemoraneous structures (compared with the rest of the arc) with troughs especially common in their outer zone where they are filled in places by flysch deposits; however, flysch deposits are also known from the interior parts, as in the Crimea and Greater Caucasus.

Areas of coupling or intersection of the arcs are marked by evidence of higher igneous activity and concentration of intrusive formations. They should be of great interest because of the relationship between igneous activity and metallogeny.

Let us take up some facts which suggest the possibility of localization of the arcs of folding. The first group of facts is represented by well-known folded and faulted structures in some arcs which are recumbent and overturned in a direction away from the interior of the arc. In a combination of several arcs, the overturning is present in some arcs and is not as conspicuous in "arcs" oriented in another direction. It is obvious that the latter "arcs" are not there at all, and only our inadequate knowledge of geologic structure in the arc segments so linked sometimes makes us mistake the linking loci of true arcs for the arcs oriented in a different direction (Figure 1). Unfortunately, this criterion for the direction of overturning, while very distinct in places, is poorly expressed in the others because of the usual fan-shaped arrangement in folded structures. For this reason, it is not always possible to ascertain the prevailing direction of overturning. It is well known, for example, that many students of the Central Caucasus have assumed a southerly direction of overturning of its principal tectonic structures. Only the past few years' study has shown the error of that assumption.

The second group of facts bearing on the possibility of localization of the arcs can be discovered on detailed geologic maps showing distinctly the intersection of tectonic lines at the junctions of arcs. As an example, we cite Ye. A. Kuznetsov's study of the junction area of the South Uralian and North Uralian arcs, between Kyshtym and the Syserta massif (Figure 6). Here, south-southwest of Kyshtym, passes the Mias-Kyshtym right lateral fault, trending north-northeast, with a horizontal displacement of 7 km. The southwest boundary of the Syserta granite massif is the beginning of the Degtyarsk left lateral fault, trending north-northwest with a horizontal displacement as much as 80 km. Originally, before understanding the localization of the arcs, and before a careful analysis of detailed maps, it was believed that both faults could be fitted into a single arc convex to the east. At the present time, it is quite obvious that such an arrangement is impossible because the Mias-Kyshtym fault is definitely traceable considerably farther north-northeast of its expected junction with the Degtyarsk fault. Other facts, such as the obvious relation of the Mias-Kyshtym fault to the South Uralian arc of a deep

...inian fault, as well as the south-southwest ...e of the folding level away from the Kysh-...Syserta area toward Beloretsk and Zilair, ...de an adequate basis for localization of the ...rcs and preclude the linking of the Degt-...k and Mias-Kyshtym faults into a single

... Regularity in the orientation of arcs with ...ions to ancient platforms. Localization ...lded arcs or, what amounts to the same ..., of deep faults, makes it possible to postu-...the following very important regularity for ...nic movements. It appears that such arcs ...either convex toward stable ancient Archean ...wer Proterozoic continental platforms and ...principal oceanic ones or they protrude con-...rably in a direction tangent to these plat-...ns, to form the loops of present oceanic ... such as the central and south Antilles (Fig-...7) and the Banda Sea Archipelago. Fossil ...s are known to be widely distributed in ...ed structures of West Siberia and the Alpine ...ope. A reverse orientation of arcs, con-... toward the stable bodies of ancient plat-...ns and convex toward mobile belts, is un-...wn to this author.

... Median massifs and some considerations ...he principles of their genetic classification. ...much as every mobile belt is always lo-...ed between two ancient platforms, either ...tinental or oceanic, it is expressed in the ...nation of folded arcs convex, usually in ...osite directions (only in loops does this re-...onship partly lose its identity). This fea-...e of the structure of mobile belts opens up ... possibility of distinguishing median mas-...s located between two nearest arcs convex ...ard two opposite ancient platforms, from ...se located between two similarly oriented ...s and from those unaltered platform blocks ...ered by arcs having encroached especially ...se to a platform. In such an analysis, the ... of initiation of the arcs and the age of the ...ucture of the massif itself should be taken ...o consideration. Therein lies the possibility ... a detailed age and genetic classification of ...jor structural elements of mobile belts, ...ich is of substantial interest, especially in ... field of metallogeny.

7. Regional structural analysis, a new ...thod of geotectonic study. What has been ...id above carries the promise of a means for ...ologists to analyze the origin and develop-...ent history of local tectonic zones in the ...ht of general regional features of the struc-...e and history of folded arcs.

It is well known that geotectonics, in reach-... for its conclusions, leans heavily on the ...thods of paleogeography and thickness anal-...is, the study of the formation and distribution ... facies and sedimentary bodies, and the anal-...is of deformation, as used in structural geology, geomorphology, and the study of recent tectonic movements. However, these methods do not achieve a comprehensive analysis of all geotectonic crustal features. There are, therefore, reasons to believe that a determination of basic regularities in morphogenesis and the development of deformation in fold belts will provide a new tool for geologists working on problems of structural geology and geotectonics and related problems such as that of industrial minerals. This new tool, and we believe a promising one, should be called the method of regional structural analysis, in analogy with the methods of microstructural and petrotectonic analyses (B. Sander, H. Cloos) used in structural geology.

8. Pinpointing the age of deformation in folded belts by methods of regional structural analysis. A new and very important element, introduced in geotectonics in connection with the concept of folded arcs associated with the arcs of deep faults, is a new interpretation of the development of fold belts. The popular ideas on the age of fold belts, as represented on tectonic maps, are inadequate for practical purposes because they reflect on the whole only the last major stage of tectonic deformations which have shaped and reshaped a given structural belt. Represented very poorly on tectonic maps, or not represented at all, are older tectonic structures whose identification has been very difficult if not impossible, up to now, because of the fragmentary information available. If, however, we take into consideration the regularities in the arrangement and development of folded arcs and the deep fault arcs controlling them, it becomes considerably easier to put together the unrelated data on ancient structures and forecast the distribution of ancient tectonic elements within younger fold belts. It also may be possible to determine the direction of migration of deep fault arcs of different ages, with relation to the cores of platforms within mobile belts.

A preliminary analysis of data suggests the lack of simple regularities in this process. Along with he amazing stability of some of the best-expressed deep faults, there are definite examples of migration (or rather wandering, to denote the change in the direction of migration) of deep faults over a broad segment of a mobile belt, either to the center of such a belt or toward the cores of continental and oceanic platforms. As yet, a preliminary consideration of this problem has failed to yield any definite regularity in the change in direction of wandering of deep faults within a mobile belt. Many specific younger deep faults are located consecutively farther away from a continental platform (Indonesia, East Australia, the Caucasus). There are probably just as many younger deep faults that not only did originate near continental platforms but also broke up their peripheral parts, thereby enlarging mobile belts at the expense

of platforms. Especially interesting in this respect is the immense belt of newly formed Laramie deep faults along the west periphery of the North American platform. Detailed geologic studies have revealed that these deep faults were formed in segments not subject to any serious tectonic deformation for at least 500 million years, and for no less than one billion years in some instances.

9. The concept of geanticlinal zones and mobile belts. The contrasting of geosynclinal segments of mobile zone with so-called geanticlinal and less mobile zones is not always justifiable. In view of the fact that nascent deep faults, a common and typical phenomenon, sever the less mobile crustal segments with their different structure and history, such diversified mobile segments, different in their internal structure and origin, should not be lumped together under the single term geanticline. It is necessary, especially for the purpose of metallogenic studies, to be able to systematize properly the several types of slightly mobile segments rather than retouch their specific features through the application of the collective term geanticline.

CONCLUSION

Such are, in their preliminary aspect, the momentous problems of geotectonics, which arise in connection with the study of folds and deep faults which form a system of arcs, and their peculiar laws of motion and development.

We should like to conclude this paper with the following observations.

First, all of the above exposition is nothing but a more or less substantiated hypothesis, for the time being. A further study may render substantially more precise the suggested concepts on regularities in the development of and the movement within deep fault zones. The publication of this hypothesis is timely: it will draw a wide circle of students to its verification and development.

Second, the author by no means intends to put his views and the study methods on morphology, origin, and history of crustal structures in opposition to the vast experience and well-developed methods of compiling tectonic maps, long in use in the Soviet Union. Such new methods should complement rather than replace the existing methods of tectonic analysis.

Third, in attaching great significance to tectonic movements in deep fault zones, we fully realize that there are a number of other tectonic movements which are responsible for the formation of various tectonic structures in platforms and geosynclinal provinces.

Although this paper treats chiefly the prob[lems] of morphogenesis of tectonic structures, the author has striven in his analysis of material t[o] take into account all data available on geologic conditions and the genesis of the structure of fold belts. It goes without saying that it was impossible to cite all these data in a magazine article.

All these reservations and qualifications mu[st] not detract from the basic fact that there is a new and very promising method of geologic stu[dy] that of regional structural analysis. We believe that this method will be a step forward in solvin[g] such most important problems as the geologic structure and history of development of mobile belts, and the features of their metamorphism, igneous activity, and metallogeny.

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ON THE PRESENCE OF A DEEP FAULT IN THE SOUTHEASTERN CAUCASUS[1,2]

by

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This paper presents the author's concept on the East Caucasian (Adzhikabul-Mardakyan) trans-se deep fault trending northeast for more than 1000 km. It is the author's opinion that the pre-nce of a major fault, concealed at the surface, is confirmed by tectonic, stratigraphic, paleogeo-phic, and paleogeologic data.

* * * * *

It often happens that tectonics of east Cau-sus is studied in detail for each small pro-ce or region, on the basis of local geologic tures and without regard to the geology of er regions. It also happens in such a study t some secondary details of the tectonic ucture of a given area, are camouflaged by se of a primary importance. However, such condary details may recur in other areas, reby taking on a more general tectonic as-ct, important for many areas and provinces.

In this connection, it is of interest to con-der the northwest fringe of the south Caspian ough, as a major unit, without differentiating into individual areas and regions.

Without pausing for the generally known tec-nic features of the upper structural (more ecisely, upper topographic) stage of south-stern Caucasus, we turn to a brief analysis tectonic, stratigraphic, geomorphologic, leontologic, geodetic, and seismic data. We all consider the information available from fferent points of view, all suggesting that a ep fault has been and is now one of the essen-al structural elements in the southeastern part the Caucasus, and has affected its long his-ry. We identified this fault between 1954 and 957, in our study of qualitative data on folding d on the distribution of mud volcanoes in east zerbaydzhan, and we described it partly as the ep transverse Adzhikabul-Mardakyan fault 23]. This name is used in the present paper here the presence of such a fault is more or ss comprehensively substantiated.

This deep fault trends from the southwest to the northeast and crosses the Lower Kura plain of Kobystan, Apsheron Peninsula, and Apsheron Achipelago (Figure 1). In the southwest, it passes approximately through the Adzhikabul area, north of Kyurovdag, south of Kharami, crosses Pirsagat River to enter Kobystan, where it more or less crosses the Baridash fold, on to the northwest part of the Touragay fold, west of the Utal'ga and Shikhikain folds, then enters Apsheron Peninsula. Here it passes north of the Shongary, Sarynch-Gyul'bakht, Kergez, Puta-Kushkhanin, Lokbatany (approximately across the north flank of the Gezdek trough), and Shabandag and Sulutepin folds. Farther on, upon entering the south limbs of the Binagad, Balakhany-Sabunchi-Ramany (crossing it approximately in the Ramany area), and Buzovninsk folds and skirting the Surakhany and Kalinsk folds in the north, it then passes over to Apsheron Archipelago where it crosses the Mardakyan fold, runs north of Artem Island and Darvin bank folds to the Andriyevskiy bank and apparently continues farther northeast.

The northeastern part of the Apsheron Peninsula (approximately in the vicinity of the Buzovny and Mardakyan folds) possibly underwent in the past large lateral displacements (in a direction different from that of the Adzhikabul-Mardakyan fault) which have shifted immense bodies of rock over considerable distances. Such shifts could have led locally to a deviation of the boundary between rocks differently striking (on either side of the fault) from the rectilinear trend of the deep fault.

The Adzhikabul-Mardakyan fault is a boundary between two sharply different trends of folds. Northwest of it (in the Kobystan-Sumgait tectonic belt or block), the folds are characterized by an approximately Caucasian to latitudinal

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[1]Offered for discussion. G.T.

[2]O nalichii glubinnogo razryva na Yugo-Vostochnom avkaze.

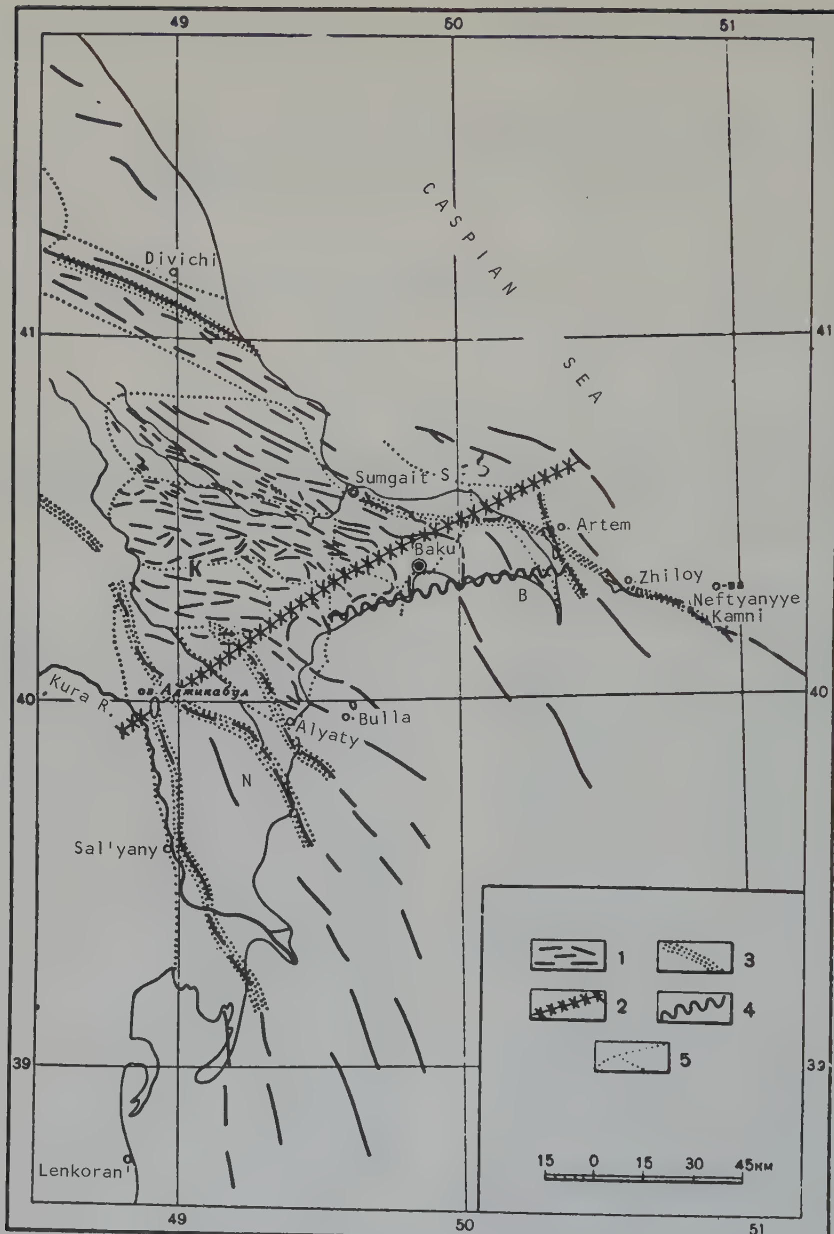

FIGURE 1. Tectonic scheme of east Azerbaydzhan

1 - anticlinal folds; 2 - Adzhikabul-Mardak'yan deep fault; 3 - zones of major faults; 4 - South Apsheronian structural shelf; 5 - boundaries of tectonic zones, regions, and provinces, K — S, Kobystan-Sumgait tectonic belt; N — B, Lower Kura - Baku tectonic belt.

axial trend, while southeast of it (in the Lower Kura - Baku tectonic belt or block) they trend southeast to submeridionally. A statistical analysis of the distribution of the axial trends of faults and their bends shows that over 2/3 of them are located in the 84 to 129° azimuth range, in the Kobystan-Sumgait tectonic block and in the 129 to 180° range in the Lower Kura - Baku belt (84% of all axial bends fall into the 84 to 141° azimuth range in the Kobystan-Sumagit belt; 85% into the 118 to 180° range in the Lower Kura - Baku belt).

The same statistics for folding indexes have

Qualitative characteristic	Kobystan-Sumgait belt	Lower Kura-Baku belt
Approximate area, km^2	7100	20 000
The aximuth range with which over 2/3 of all bends in the trend of the fold axes in the belt are associated, in degrees.	84—129	129—180
Over-all length of folds, km	1140	950
Average extent of folds for 100 km^2	16.1	4.8
Average distance between the axes of adjacent folds, in km	6.2	20.8
Density of folds (number of folds for 100 km^2)	2.1	0.5
Predominant trend of folds	Latitudinal to Caucasian	Southeast to nearly meridional

wn that the number of folds and the distance veen them are different for the two sides of deep fault: the average distance between axes of folds in the Kobystan-Sumgait belt is ee times smaller while the number of folds unit of area is 4 to 5 times greater than in Lower Kura - Baku tectonic belt (table).

The dip of the fault planes on the upper topo-phic level (accessible to direct observation l drilling) has a definite relationship to the e of the fault on which it is located.

Fault planes northwest of the Adzhikabul-rdakyan deep fault dip north and northeast, a rule (i. e., toward the Greater Caucasus), h north and northeast blocks commonly ust over the south and southwest ones. Dips 50 to 80° and less often occur along with al-ost vertical fault planes (80 to 90°).

Fault planes southeast of the Adzhikabul-ırdakyan fault are almost vertical or else very steeply (70 to 90°) in either direction, t mostly toward the south Caspian trough. ong the steepest of such faults, the north nk of that trough appears to have been thrust er the adjacent northern regions (such as is-nds of Artem, Gyurgyany, Zhiloy, Kamni igorenko, Neftyanyye Kamni, Kergez-zyltepe, Lokbatan, Atashkya, etc.). This rhaps suggests a shift of the Lower Kura-ku tectonic block (belt) somewhat to the rtheast along the deep fault.

Along a considerable stretch, the Adzhikabul-ardakyan deep fault presents a boundary at hich the thick Paleogene-Miocene complex de-eloped northwest of it plunges abruptly south-ast and disappears beneath Pliocene and Anthro-ogene deposits which attain here an immense ickness (over 4 to 5 km). This suggests a onsiderable subsidence of the lower stage in e Lower Kura - Baku tectonic belt (block), specially in its southeastern part (Figure 2).

The Adzhikabul-Mardakyan deep fault is characterized by its long period of development. It persisted and developed parallel with sedimentation, not only in the Anthropogene but before: in the Upper Pliocene (Apsheronian, Akchagylian), Middle (the age of the productive interval) and Early Pliocene (Pontian), Miocene, and apparently before that.

The significance of the Adzhikabul-Mardakyan fault becomes obvious from an analysis of thickness of the Anthropogene, Apsheronian, and Akchagyl stages (Figure 3). Lower Old-Caspian beds (Tyurkyansk horizon and Baku stage) were deposited on the Apsheronian Peninsula mostly southeast of the Adzhikabul-Mardakyan fault. The limit of distribution of the Baku stage in Kobystan, also coincides closely with its areal position (Figure 4). The erosion area of southeastern Caucasus in Baku time, in its extension as far as the Apsheron Peninsula and southeastern Kobystan, is abruptly cut off by the Adzhikabul-Mardakyan deep fault. It is quite obvious that in Baku time the Lower Kura - Baku tectonic belt, to the southeast, was subsiding, thus suggesting the difference in geotectonic and paleogeographic conditions on either side of the fault. Isopachs showing total thickness for the middle and lower division of the Apsheronian approximately follow its trend (Apsheronian Peninsula, Kobystan).

In Middle Paleozoic time the Adzhikabul-Mardakyan fault apparently apralleled the isolines of the productive interval (southwestern part of the Apsheronian Peninsula, Kobystan).

It is important to note that only the best-expressed deep faults make a boundary for paleogeographic environments. They often divide tectonic belts or blocks located in approximately similar facies environments. For this reason, a sedimentary basin may cover up a deep fault zone, to a considerable extent. Such is the situation in the Adzhikabul-Mardakyan deep fault whose extreme northeastern and southwestern segments are covered by a sedimentary

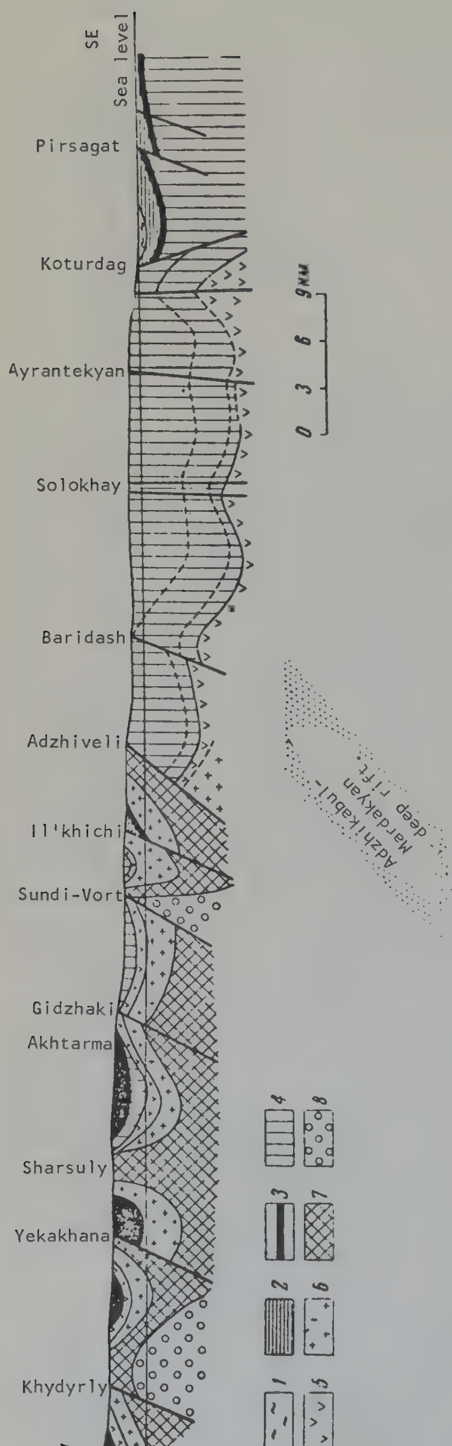

FIGURE 2. Generalized transversal cross-section of the Adzhikabul-Mardakyan deep fault (across Kobystan).

1 - Quaternary deposits; 2 - Apsheronian stage; 3 - Akchagylian stage; 4 - productive interval; 5 - Pontian stage; 6 - Diatomaceous formation; 7 - Chokrak-Spirilis beds and Maykop formation; 8 - Koun formation.

basin responsible for the deposition of the productive interval. (Here, the productive interval has extended considerably west of the fault, where it is represented by a substantially different facies complex.)

The Adzhikabul-Mardakyan deep fault coexisted with sedimentation not only in the Pliocene and Anthropogene but before that, as well (e.g. in the Miocene). Its effect in the Meotian and Chokrakian is noticeable in the arrangement of the nearest Caucasian shores of paleobasins[3] to he northwest and parallel to it. Not much can be said of the Adzhikabul-Mardakyan fault in the more remote past, because older sediments have not been uncovered in a considerable area southeast of it, as yet, and nothing can be said about their distribution. However, the age of this fault undoubtedly is pre-Miocene and probably pre-Paleogene.

The south-southeasterly regional thickening of formations in the Apsheron Peninsula is especially conspicuous near the Adzhikabul-Mardakyan fault. For instance, in the south-southeast trending Biba-Gousan trough, where it is crossed by the deep fault, the rock thickness gradient is 1.5 to 2 times higher, attaining 90 to 140 m/km for the productive interval (between boreholes 710 and 1258). A considerable increase in thickness near the rift has also been observed at its crossing of the Kirmaku-Balakhany-Sabunchi-Surakhany-Karachukhur anticlinal zone, whose folds (as is true for other folds of the peninsula) were growing simultaneously with sedimentation; this has considerably modified the regional rate of thickening and the possible deviations from it. Withal, the thickness gradient at the fault rises abruptly to 200 or 250 m/km and more (near boreholes 969, 2399, 971, 1107), while it is considerably lower both north and south of there (within the anticlinal zone).

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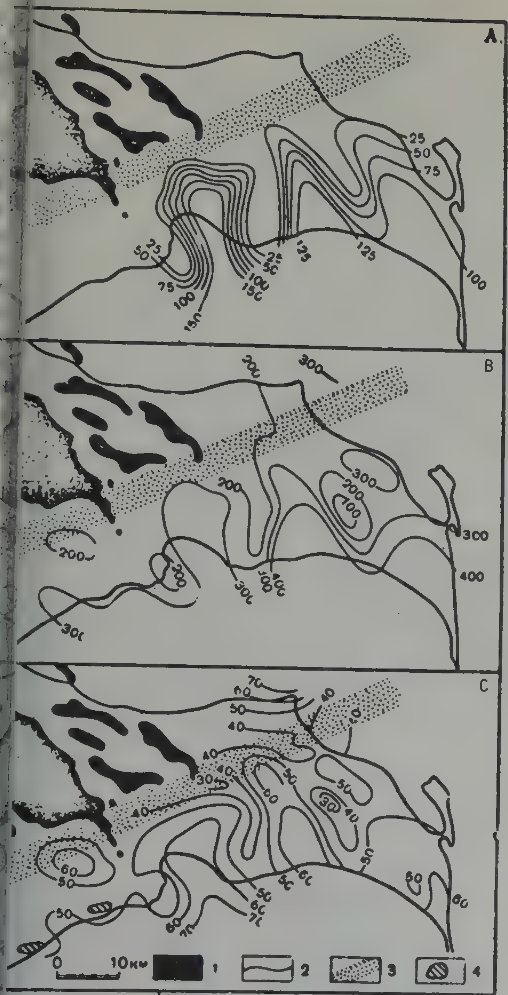
[3]In the Miocene, when paleogeographic conditions were more complicated and terrigenous material arrived at Kobystan (where the Adzhikabul-Mardakyan fault passes) from the south as well (Shirvan geanticline), the Adzhikabul-Mardakyan fault also left its trace in paleogeographic conditions of sedimentation: In the Karaganian, Konkskian, and Sarmatian, the boundary between the northern argillaceous and the southern arenaceous facies trended east-northeast [2], i.e., approaching the Adzhikabul-Mardakhyan trend and, what is more, it was located near the latter. Thus the very similar distribution of the boundaries of various Karaganian, Konkskian, and Sarmatian lithofacies in Kobystan appears to have nothing to do with the Caucasian trend of the paleoshores of the source landmass - the Shirvan geanticline. At the same time, it shows the tendency to conform with the trend of the Adzhikabul-Mardakyan deep fault which cuts the Shirvan-source landmass in an almost transverse direction.

(Incidentally, such a distribution of Miocene facies also points to the insignificant part of the Shirvan land as a source of sediments; that land must have been very small, possibly only an insular uplift).



GURE 3. Change in the thickness of the lower part of lower division of older Alpine (A) deposits of the Apsheronian), and Akchagylian (C) stages on the Apsheron Peninsula [19].

- Paleogene, Miocene, Pontian; 2 - isopachs; - Adzhikabul-Mardakyan deep fault; 4 - zones f zero thicknesses of the Akchagylian stage.

The Adzhikabul-Mardakyan deep fault is a ocus of most zones where the Pontian was roded prior to deposition of the productive orizon, while Pontian deposits northwest and robably southeast of it were not fully eroded. This suggests that immediately before the eriod of the productive interval, the zone djoining this deep fault (especially in the west) tood high and was intensively eroded.

The Adzhikabul-Mardakyan deep fault is lso reflected in the distribution of folding. Thus Late Pliocene and Anthropogene folding n southeast Caucasus was developed mostly outheast of the fault which appears to have acted as a screen to the spreading of folding west of it[4] (Figure 5).

On the Apsheron Peninsula, all large and deeply subsided troughs (the Baku, Gousan, Zyrinsk) are located southeast of the Adzhikabul-Mardakyan fault; conforming to its northeasterly trend, the troughs farther east also extend farther north.

The most recent Anthropogene movements of the region also display a definite relationship to the trend of the fault in the parallel orientation of topographic contours, as in the Old Khvalynsk terrace (Figure 5). Consequently, epeirogenic movements, too, have occurred in conformity with the trend of the deep fault, normal to which the elevations of contemporaneous formations show their highest gradient.

An analysis of recent tectonic movements on the Apsheron Peninsula also points to the importance of the Adzhikabul-Mardakyan fault which appears to be a line of demarcation between two, usually opposite, directions of vertical movement.

A study of vertical crustal movements in the Apsheron Peninsula on the basis of high precision relevelling affords a determination of the intensity and direction of these movements in various regions and in relation to the fault. A comparison of the 1912 and 1928 levelling bench marks after N. N. Bol'shakov [3] and G. R. Bregman [4] shows that the northwestern part of the Apsheron Peninsula is rising (at an average rate of 1 to 3 mm per year) while its southeastern and southern parts sink (at an average annual rate of 1 to 5 mm). It is significant that the boundary between the two movements almost coincides with the Adzhikabul-Mardakyan fault. This is an independent and weighty argument for the presence of such a fault within the Apsheron Peninsula (Figure 6). The Kobystan-Sumgait tectonic block northwest of it is rising while the Lower Kura - Baku block is sinking. The sharp change in the rate and direction of vertical movements coincides with the locus of the deep fault.

The 1936, partial high-precision relevelling of the Apsheron Peninsula by the Trans-Caucasian Trust [5] showed that the rate of vertical movements increased sharply between 1928 and 1936, which emphasizes the differential character of these movements on either side of the fault. The rate of the land rise northwest of the fault increased two to three times. This rise locally involved adjacent areas of the zone

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[4]The buried Adzhikabul-Mardakyan fault lies probably 5 to 7 km deep or deeper (approximately below the entire thickness of Cenozoic deposits) below the zone of its manifestation (where the quatitative folding indexes undergo an abrupt change).

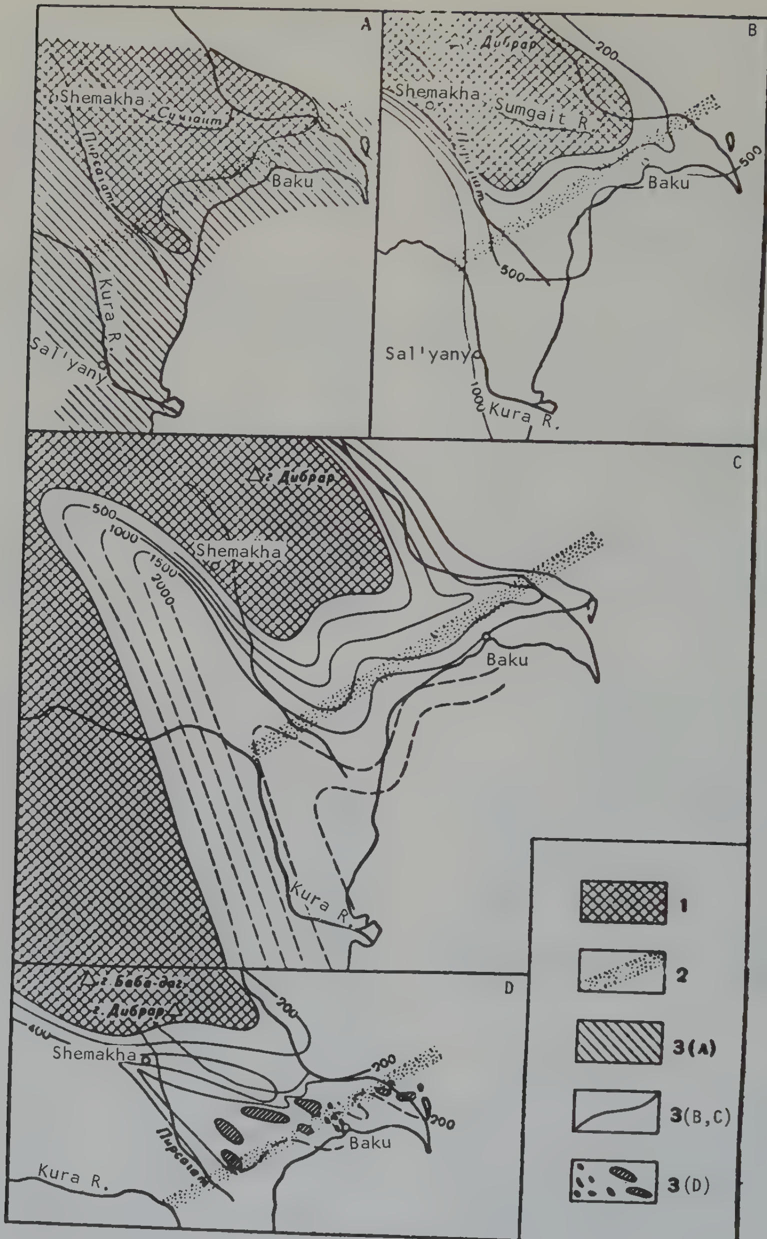

FIGURE 4. Distribution of the Baku stage (A); of the thickness of the Middle and Upper Apsheronian stage (B); of the productive interval (C); and the Pontian stage (D) [27].

1 - erosion area; 2 - zone of the Adzhikabul-Mardakyan deep fault; 3 - Baku stage (a), isopachs (B,C) and zones without Pontian deposits as a result of erosion before the era of the productive interval (d).

marking the change in the sign; a local intensification of sinking has been observed along with that of rising.

Even in such an obviously geosynclinal province as the Apsheron Peninsula, the earth's crust exhibits a semblance of block structure, with the blocks displaced on either side of the fault. It should also be kept in mind that the difference in the intensity of vertical movements within a block is much smaller than that between the blocks (aside from directional differences).

A sharp intensification of the sinking within comparatively small individual areas of oil fields has long been known [3, 4]. The average rate of

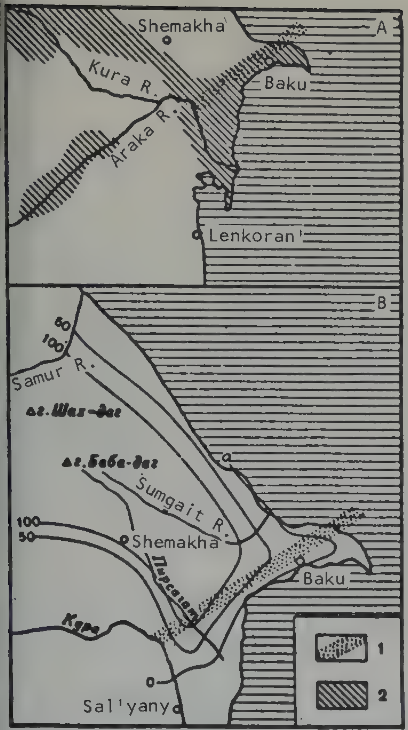

FIGURE 5. Distribution of folding in the Pliocene and Anthropogene (A), after [29], and elevations of the Upper Khvalynsk terrace (B), after [27]

1 - the Adzhikabul-Mardakyan deep fault zone; 2 - Upper Pliocene and Anthropogene folding.

king for bench marks in oil fields, between 2 and 1928, was 9 to 14 mm per year in the ieybate, Balakhany, and Sabunchi, and 15 to mm per year in the Surakhany and Ramny. us, the rate of sinking for bench marks within fields is 5 to 10 times higher than that in ad- ning areas of the subsiding tectonic block.

This sharp rise in the rate of sinking for me oil fields is often connected with an inten- ied oil production and the corresponding sag- g of ground (oil fills only the pose space in ck). To what extent this is true, we do not yet ow.[5] If the withdrawal of oil has any effect on subsidence of oil lands, they will be even ore affected by the withdrawal of a large vol- ne of formation water and, to a certain extent, sand.

Finally, considerable vertical movements are characteristic of mud volcanoes. For instance, bench marks near the Lokbatan volcano rose 0. 83 m between in 1912 and 1928 (up to 50 mm per year) while they sank by 3. 28 m (205 mm per year) at the Bogboy which is of local significance because of the intensive quarrying under that mountain.

However, neither the subsidence of oil fields nor the wide range of changes in the altitude of mud volcanoes can alter the general picture of vertical displacements in the earth's crust on the Apsheron Peninsula.

The nature of recent epeirogenic (oscillatory) motion of the earth's crust in the east Caucasus (and not on the Apsheron Peninsula alone) also points to the presence of a deep fault on the Apsheron Peninsula. A. A. Izotov's correlation [11] of the relevelling (1936) along the Makhach-kala-Baku railroad line with that of 1912 (1910 to 1914) revealed considerable and regular vertical displacements in east Caucasus, amounting to 360 mm in 23 years, with the uplift center at Nasosnaya station (compared with the land uplift at Makgachkala where it is assumed to be zero). From Makhachkala to Baku, the vertical eleva-tions first increase (as far as Nasosnaya and Sumagit stations) then decrease (Figure 7). How-ever, the decrease in elevations southeast of Khurdalan is very sharp and again is associated with the Adzhikabul-Mardakyan fault. Northwest of the fault, the rate of vertical movements (12 to 15 mm per year) is two to four times higher than that southeast of it (4 to 6 mm per year).[6] In the Masosnaya-Bailov Point section, the inten-sity of vertical movements is abrupt (step-like) rather than gradual.

The effect of the Adzhikabul-Mardakyan fault can be determined to some extent also from a comparison of the 1909-1910 levelling and the 1936 [13] relevelling results along the Yevlakh-Alyata railroad section. It shows an uplift (+23 mm) at Mugan' station (Figure 8) (and east of the Adzhikabul-Mardakyan fault) against a general subsidence along the entire north flank of the Kura trough (in relation to the Kronshtadt tidal gauge). At the same time, a maximum subsidence for the entire line (-296 mm) has been observed

[5]The following computations can be made: between 12 and 1928, some 48 million metric tons were pro-ced in the Balakhany-Sabunchi-Ramany field. For same period, the field bench marks sand about 2 m, which corresponds to a volume loss of about 6 llion m^3. This is only about 1/8 of the produced oil lume. Approximately the same is the corresponding tio (10 to 20%) for the Surakhany and Bibieybate lds. The lowering of the bench marks is possibly affected by what may be called "shaking down" of the oil field ground (primarily its top layer) caused by microseismic phenomena in connection with continu-ous activity of the heavy machinery. In that event, higher ground will be the most affected. It is also possible that some effect is exercised by the continual subsidence of the crestal segments of folds, along fault planes [28].

[6]In the entire east Caucasus, between Makhachkala and Baku, there is only one zone of sharp change in the rate of vertical movements, and consequently only one deep fault zone. There are no other similar (in their present intensity deep faults in the east Caucasian coastal zone. Other deep faults whose presence may be suspected in east Caucasus (near Derbent, for ex-ample) are less significant and appear to have played a minor part in its geologic development.

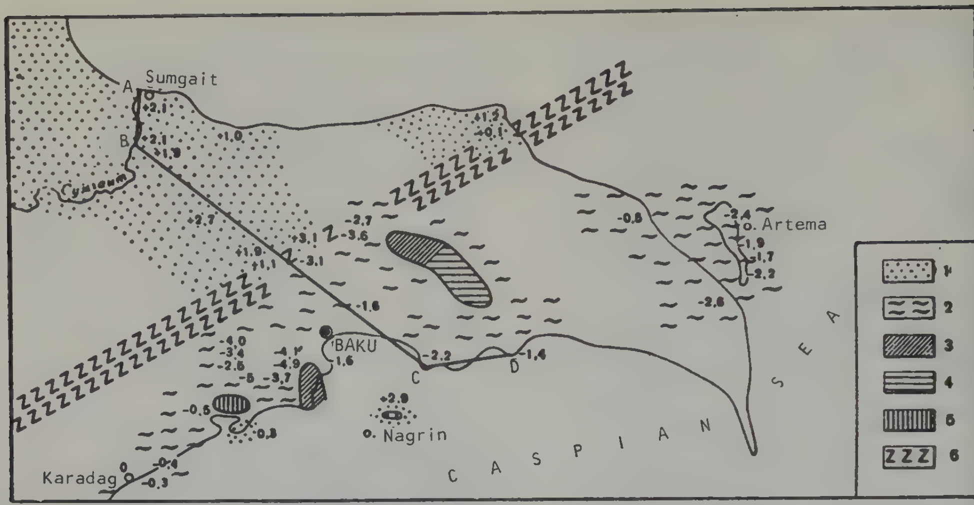

FIGURE 6. Generalized map of recent vertical movements on the Apsheron Peninsula (from the 1912-1928 levelling) and the Adzhikabul-Mardakyan fault.

1 - areas of uplift (annual rate, 0.1 to 3 mm); 2 - areas of subsidence (0.1 to 5 mm per year); 3 - oil field areas sinking at annual rate of 9 to 14 mm; 4 - oil field areas sinking at annual rate of 15 to 50 mm; 5 - mud volcanoes, intensively rising (average rate, up to 50 mm per year); 6 - Adzhikabul-Mardakyan fault.

at Pirsagat station. The southwestern segment of the Kobystan-Sumgait tectonic block, west of the Adzhikabul-Mardakyan fault,has subsided the least in the Yevlakh-Alyat section, where its central part (area of Mugan' station) has even undergone an uplift. The Lower Kura-Baku tectonic belt has subsided the most, immediately east of the fault.

According to the Ye. I. Byus earthquake catalog [6], there is a group of epicenters in the Caspian Sea, north of the Apsheron shelf, with a tendency to be concentrated within a northeast-southwest trending zone, approximately toward the Sumgait mouth[7] (previously unknown earthquake epicenters are possibly present here). A southwesterly projection of this line coincides with the Araks course in its Mindzhevan-Sabirabad stretch (before its confluence with the Kura). A transverse downwarp, large for the East Caucasus, with an anti-Caucasian trend and related to the course of the lower Araks (approximately from Megra to Mindzhevan, before the river enters the plain), was in existence as early as the beginning of the Pliocene and developed later on, especially in the Late Pliocene and Anthropogene [29].

The Adzhikabul-Mardakyan fault, now recognizable primarily in the anture and direction of folding which affects Pliocene and Anthropogene deposits and which are most intensive in the Anthropogene, had been exposed in the past (Pliocene) directly to the west. This warrants the assumption that the lower Araks downwarp is a deep reflection of the projection of this fault. In the course of time, as the sedimentation proceeded, the trough kept subsiding, accompanied by the formation of a new trough (sic), while the rift scar at the surface of newly-deposited sediments continued to be displaced toward the rising block.

Should an earthquake related to the deep rift occur in the area of the lower Araks downwarp, its focus would be found at a depth corresponding to that of the intersection of the vertical trough with that point of the downwarp and the deep fault plane.[8]

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[7]As noted by N.V. Malinovskiy, the Apsheron Peninsula is also affected by earthquakes originating underneath the Caspian Sea. These earthquakes exhibit "a linear arrangement of epicenters along a southwest-northeast trend" ([14], p. 46).

[8]Assuming the depths of the Caucasian earthquake foci at 10 to 60 km [20], and considering the association of the seismic zone (where a number of epicenters have been noted) with the lower Araks downwarp and especially its northeasterly extension under the Caspian Sea, the dip of the fault zone toward the Caucasus can be calculated. It turns out that the Adzhikabul-Mardakyan fault dips northwest toward the Greater Caucasus at an angle of 22 to 67^0. With the average depth of the foci of the Caucasian earthquakes assumed to be 15 to 35 km, the corresponding dip of the fault plane is 30 to 50^0. The probability of a 30 to 50^0 (average 37^0) dip increases because the two known foci of earthquakes associated with the lower Araks downwarp [20] have a depth of 25 km (with a corresponding fault plane dip of 36^0). The focus of the April 9, 1935 very deep Caspian-Caucasian earthquake (150 km deep; coordinates after Ye.I. Byus: $\varphi = 42^0 14'$; $\lambda = 48^0 48'$) is associated with the northwesterly plunge of the Adzhikabul-Mardakyan. This is a startling fact. However, this author is far from relating the Caspian earthquake to that fault, although the coincidence may be less accidental than it is thought.

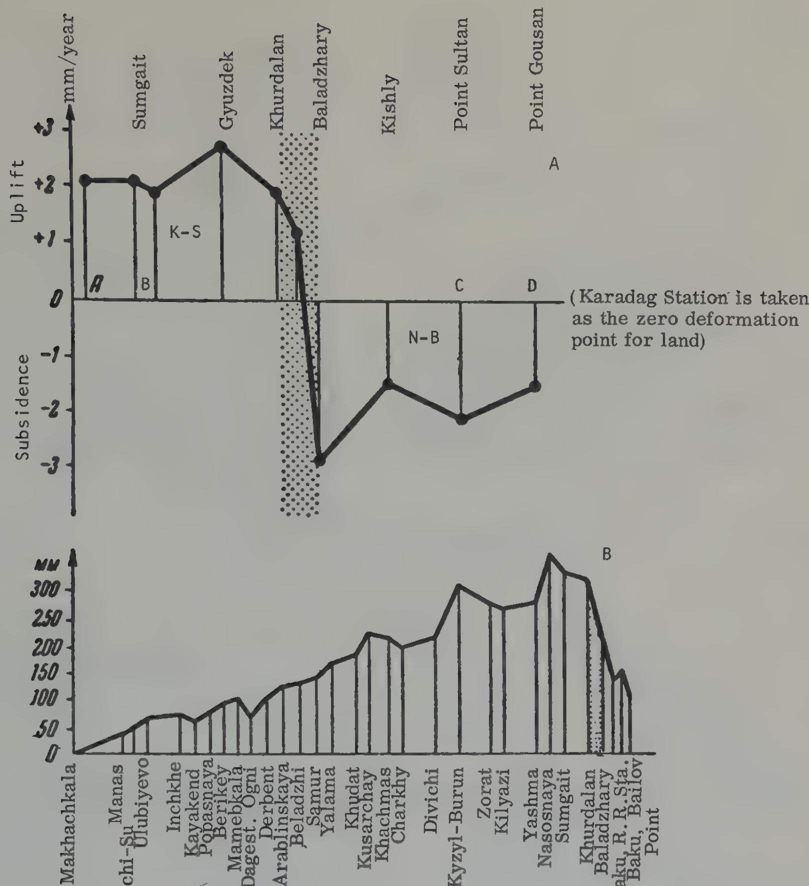

FIGURE 7. Change in the elevation of points on the Apsheron Peninsula as a result of recent vertical movements on either side of the Adzhikabul-Mardakyan deep fault, along ABCD (A), and changes in the bench mark elevations between 1910 and 1936 as relevelled along the Makhachkaly-Baku railroad lin line (B).

K — C, the Kobystan-Samgait tectonic belt; N — B, the Lower Kura - Baku tectonic belt. Dotted band - the Adzhikabul-Mardakyan fault zone.

These data show that the plane of the Adzhi-bul-Mardakyan fault has a definite dip char-teristic, according to A. V Peyve [17, 18], mobile belts in contrast to platforms where eep faults are usually formed.

Incidentally, the determination of the Adzhi-abul-Mardakyan fault is essential for seismic tudies (in the Apsheron Peninsula). The most azardous areas, seismically, are associated ith this fault;[9] however, the earthquake foci here are very shallow (several kilometers) and are associated with the uppermost sedimentary sequence (chiefly Genozoic). Their depth increases northwest of the rift, with depth. The Adzhikabul-Mardakyan fault may also turn out to be a fairly sensitive absorber of seismic shocks originating in foci northwest of it (the Shemakha, for instance); in that event, the intensity of earthquakes to the southeast must be much lower and the isoseismic lines in that direction may turn out to be considerably deformed.

The presence of the Adzhikabul-Mardakyan fault is reflected in geomorphic features of adjacent areas. Orographically, southeast Caucasus appears to be "cut-off" by this fault, with the terrain southeast of it usually below the +200 m contour. The shallow water isobaths in the northwest fringe of the south Caspian basin

[9]We note parenthetically that the strongest known psheronian Peninsula earthquake (January, 1842) ccurred precisely in the Adzhikabul-Mardakyan fault one [6]. That earthquake was felt (or took place) in any localities of the peninsula; at Mashtagi and abrat (i.e., near the rift) it recurred on many ccasions.

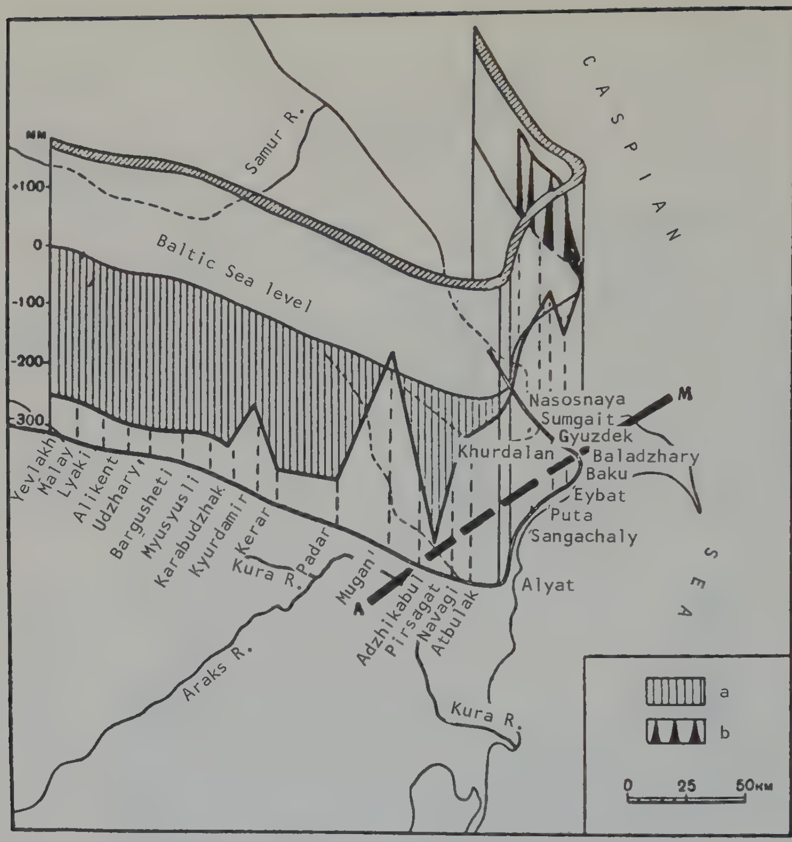

FIGURE 8. Vertical movements in east Trans-Caucasus (1909 to 1936) and the Adzhikabul-Mardakyan fault. Shown is the change in elevations of bench marks (from the 1909 to 1913 and 1936 levellings) along the railroad line from Yevlakha in the west to Alyata in the east and Nasosnoye in the north (The Baltic system of elevations).

a - lowering of elevations; b - rising of elevations; A — M, Adzhikabul-Mardakyan fault.

also run parallel to the Adzhikabul-Mardakyan fault. Its lower Araks segment is clearly expressed, geomorphically, in the Araks valley trough, while the Caspian (submarine) segment is defined by the sharp bend of the isobaths, which are normal to the fault, but veer sharply in the vicinity of it and run obliquely to it[10] (the 500, 400, and 300 m isobaths).

Associated with the Adzhikabul-Mardakyan deep fault, as we have already noted [23], is a zone of powerful east Azerbaydzhan volcanoes (Bol'shoy Kyanizadag, Touragay, Kalmas, Otmanbozdag, Kyurovdag, Koturdag, Cheildag, Baridash, Ayrantekyan, Malyy Kyanizadag, Mishovdag, Lokbatan, Keyreki, Davalidag, Cheilakhtarma, Akhtarma-Pashaly, Tashmardan, etc.). The largest volcanoes, as well as those of any significance, of the Apsheron Peninsula are located either in the deep fault zone itself or else immediately near it. Away from the fault, the number and dimensions of mud volcanoes decrease appreciably, with chiefly mud sopkas and cones developed.

The zone of higher salinity of mud volcanic water coincides with the Adzhikabul-Mardakyan fault zone [22]; the latter also appears to control the distribution of the composition of gases emanating from the interior.

In 1958, L. K. Tatevosyan, in her study of deep crustal structure from gravimetric data, pointed out that "a characteristic lowering of the Tertiary-Mesozoic boundary, from 8 down to 12 km, is present in the Apsheron Peninsula are. The gravity field in that area is marked by a consistent northeast-southwest trend of isolines, with high horizontal gradients of the gravity

[10]By the way, the earthquake foci in the western part of the central Caucasus are usually associated with an abrupt deepening of the Middle Caspian trough, i.e., with a bathimetric escarpment which probably suggests the presence of a west Middle Caspian fault, here, with a southeasterly submarine trend.

malies. This step-like subsidence. . . . has n traced southwest across the entire western of the peninsula (between Fat'mai and sany)" ([25], pp. 7-8). It follows that an arpment on the Mesozoic-Cenozoic contact is sent between Fat'mai and Gousay, which codes with the trend of the Adzhikabul-Mardak- fault.

n considering gravity anomalies of east erbaydzhan, R. M. Gadzhiyev noted in 1958 : "some of the isoanomalies, forming a vity step veer southeast out into the sea and line the area of maximum subsidence of upper ers of the earth's crust. The axis of this wnwarp passes through Ali Bayramly and Maryany ([8], p. 143). Considering that Ali Baynly is located near Adzhikabul Lake, it turns that the axis of this downwarp exactly coines with the Adzhikabul-Mardakyan fault; conquently, the axis of maximum subsidence for the entire upper sedimentary complex of the crust coincides with that fault. The fault and the area affected by it played a very significant part in sedimentation, not only in the Cenozoic but in the Mesozoic and older periods.

Thus, associated with the Adzhikabul-Mardakyan fault is the axis of maximum subsidence of the upper crustal layer, on one hand, and a step in the subsidence of a sedimentary sequence (as expressed in the top of the Mesozoic and probably extending considerably deeper, in older stratigraphic systems).

The Adzhikabul-Mardakyan fault extends for a considerably distance. From Adzhikabul to the Apsheron Archipelago alone, it is 150 km long. Considering, in addition, its southwesterly extension as the lower Araks trough and the Caspian Sea seismic zone to the northeast, its over-all

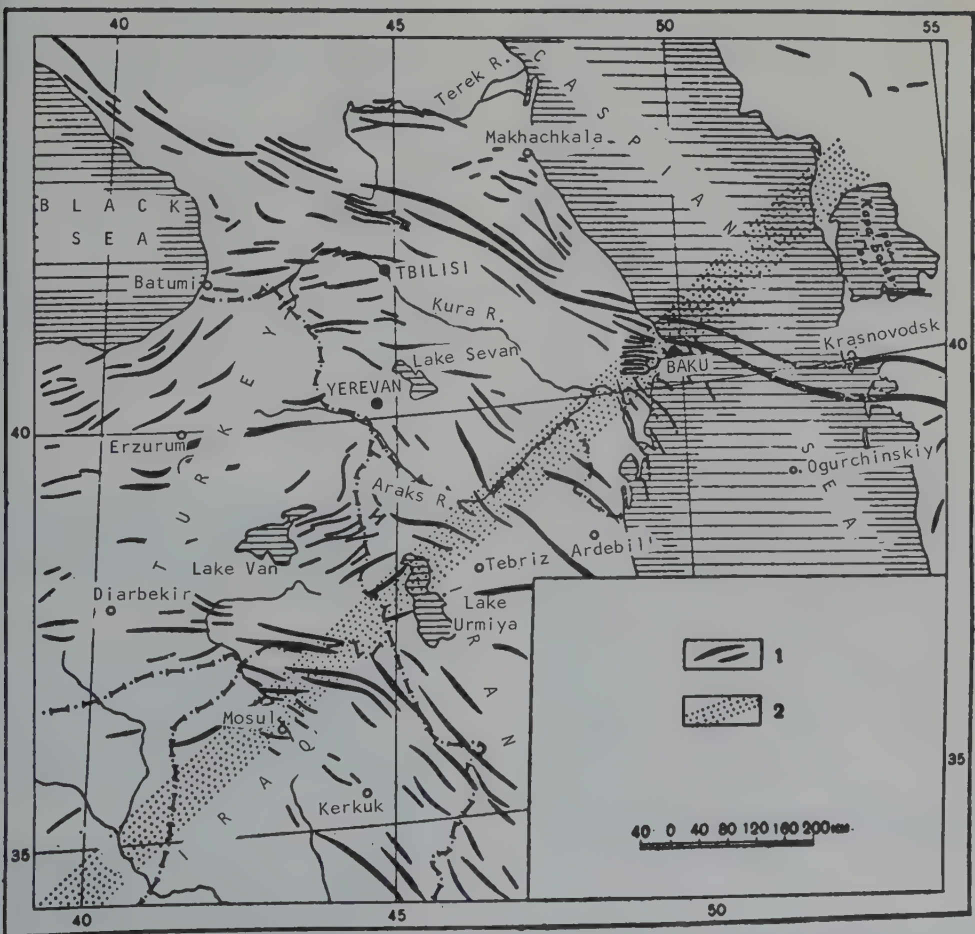

FIGURE 9. Structural trends in the vicinity of the east Caucasian transverse fault (copied from the Tectonic Map of the USSR [26] with detailing for east Azerbaydzhan and the Caspian Sea).

1 - anticlines and anticlinoria; 2 - the east Caucasian fault zone.

length exceeds 600 km. On the whole, this fault should be regarded as regional and called the east Caucasian transverse fault, characterized by its rectilinear or nearly rectilinear trend and great length.

The further northeastern extension of the east Caucasian transverse fault passes through Kazakh Bay, on the east Caspian shore, and possibly farther on. Its southwesterly extension is defined much better [26]; it is traceable across the northern part of Lake Urmiya, trending southwest near Mosul (Figure 9). Its projection, here, marks a sharp change in the structural trend. Northwest of it, the folds (anticlinoria) usually trend in a latitudinal, even northeasterly, direction; southeast of it, they veer sharply southeast (Figure 9). Thus the east Caucasian transverse fault is a segment of one of the largest deep faults, extending almost rectilinearly for 1600 km or more.

Some students postulate a deep fault along the Main Caucasian Range (as a system of en echelon disturbances), having developed for a long time (from the Jurassic and earlier and up to the present day), and especially intensively during the Cenozoic.[11] The Sevano-Zangezue deep fault [7] is described in the Trans Caucasus extending from the northwest to the southeast between the Bazum Range and the Araks, a distance of 360 km. It was active from the Jurassic to the Anthropogene. This zone, previously named the "Little Caucasus Overthrust Zone" by K. N. Paffengol'ts [15] is in effect normal to the east Caucasian (Adzhikabul-Mardakyan) fault trend. Therefore, the two fault zones constitute a diagonal system of faults whose important part in the crustal structure of the earth has been suggested by N. S. Shatskiy [30].

Thus, southeast Caucasus and some adjacent regions are characterized by a peculiar combination of processes and phenomena which convincingly suggest the development of a major east Caucasion rift. These specific processes and phenomena, each suggesting the presence of a major tectonic belt in the crust, in that particular area, are revealed primarily in tectonic features (namesly in sharp changes in the trend of folding on either side of the fault, also reflected in the quantitative indexes of folding), paleogeographic, paleogeologic, and stratigraphic characteristics; in recent and present tectonic movements; topographic and bathimetric data; the distribution of seismically active zones and areas, and areas of mud volcanism; in the history of geologic development; in the distribution of isoanomalies in the gravity field; and by other features.

All these features, as they pertain to the east Caucasus, are explained simply and naturally as they are considered in relation to a deep fault.

This deep fault has not been previously recognized as a major structural element because individual natural facts have been considered in isolated pashion without being related directly to other facts. Nonetheless, the important conclusion on the presence of deep faults in east Azerbaydzhan has already been arrived at by V. A. Gorin [9, 10], on the basis of limited data (mostly the association of mud volcanoes and fault zones, and some general information on the distribution of gravity anomalies).

In the light of the above exposition, we have postulated and substantiated the presence of an east Caucasian fault, extending almost rectilinearly for more than 1600 km, and trending southwest across the Caspian Sea, southeastern Caucasus, the Kura plain, Little Caucasus, across Iran, Turkey, Iraq, and on to Syria. It is up to future geologists to detail the structure of this huge tectonic zone, probably with a long history, which passes through provinces of different geologic structure and genesis of the upper layer of the earth's crust.

In conclusion, we note that the significance of faults, especially deep ones, in the structure of the Crimea-Caucasus-Kopet Dag fold system is much greater than has usually been thought [7, 10, 15, 23, 24, etc.].

[11]Within the northwest fringe of the south Caspian trough, V.A. Gorin [9] has identified a number of normal lateral faults in Lower Tertiary and Mesozoic sequences. Some of them he called deep faults, without considering them in detail. Closely coinciding with one such fault is the Adzhikabul-Mardakyan fault zone.

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BURIED DIABASE FORMATION OF THE VOLGA-URAL REGION[1]

by

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Rocks of the buried diabase formation are an ential constituent of the pre-Devonian inter- of the Volga-Ural region. This paper deals h their distribution in time and space, their gin end effect on the enclosing rocks, and sequently the host rocks' petroleum possi- ities.

Igneous rocks of the Volga-Ural region have en studied by a number of authors: V. P. renskiy, T. A Lapinskiy, V. S. Knyazev and M. Varentsov [14, 15, 16], K. R. Timergazin 1, 12], K. I. Lomot' [9], M. A. Garris [2], M. Dymkin, L. F. Solontsov, and S. S. Ellern], and F. S. Kulikov [7].

Rocks from boreholes Or'yebash (No. 57) and ro-Petrovo (No. 5), previously described by P. Florenskiy and his coauthors; Serafimovka o. 65), Varzi-Yatchi (No. 7), Nadezhdino (No.), and basic rocks from the Inzersk formation the Urals were studied for the purposes of s paper.

Within each age subdivision, all igneous cks have been grouped into types, with a de- iled description of contact phenomena.

STRIBUTION AND FORMS OF OCCURRENCE OF IGNEOUS ROCKS OF THE DIABASE FORMATION

So many igneous rocks have become known om various localities of Bashkiriya, Tatariya, d Udmurtiya, and so large are their dimen- ons in some places that it becomes more pro- er to speak not of isolated exposures but rather a buried diabase formation of the Volga-Ural egion as a whole, similar to the traprock for- ation, the Olonetsk diabase formation, and the arru dolerites of Africa.

The buried diabase formation occupies north nd south Bashkiriya and parts of Tatariya, Permskaya Oblast', and Udmurtiya. Its thickness is fairly great, ranging from 3.0 to 165 m (perhaps with interruptions because cores have not been taken everywhere). Some of the boreholes did not penetrate its entire thickness (Table 1 and Figure 1).

All extrusives have been encountered in upper Paleozoic rocks (the Kaltasin and Serafimovka formations), and never in the Cambrian sequence. Uncovered at some points were intrusives overlain by Lower Cambrian (Upper Bavly beds) and in places Devonian formations. In such places, they have been considerably altered by weathering.

The forms of occurrence of the diabase formation rocks have been described also by K. R. Timergazin, T. A. Lapinskaya, and V. S. Knyazev. K. R. Timergazin believes that, in analogy with the Urals, dikes are the predominant form of occurrence. T. A. Lapinskaya and V. S. Knyazev, referring to the fact that a sill-like intrusion has been penetrated by the Serafimovka boreholes,[2] believe that sills are the predominant intrusive form. We believe, in analogy with other diabase formations, that both dikes and sills occur in the Volga-Ural region.

THE KALTASINSK FORMATION

No intrusive rocks have been found in Lower Kaltasinsk beds.

Upper Kaltasinsk Beds

Mostly olivine gabbro and diabase have been encountered in upper Kaltasinsk beds. They have been described from the Or'yebash No. 57 borehole, by M. M. Veselovskaya. They were previously studied by K. R. Timergazin, also by V. P. Florenskiy, T. A. Lapinskaya, and V. S. Knyazev. A description of them is given below.

[1] O pogrebennoy diabazovoy formatsii Volgo- ral'skogo regiona.

[2] Rocks from Serafimovka boreholes Nos. 119 and 65 are somewhat different; they can be regarded as two dikes (Figure 2).

TABLE 1

Thickness, depth of occurrence, and characteristics of igneous rocks penetrated in boreholes of the Volga-Ural region

Age of underlying rocks	Age of overlying rocks	Location and No of borehole	Thickness of intrusion in m	Depth of coring, m	Description of rock	Are contact phenomena present?	Weathered Zone?
Upper Kaltasinsk	Upper Kaltasinsk	Or'yebash, 57	71	2324—2395	Olivine gabbro	In hanging wall and floor or intrusion	None
			7	2415—2422	Diabase		
			7	2478—2485	Basic rocks (from borings)		
"	Lower Cambrian	" 22	72	2010—2030	Alternating basic and sedim. rocks)	?	"
				2030—2043	Gabbro diabase	?	"
				2043—2052	Same	?	"
"	Givetian	" 14	14	2059—2073	Olivine gabbro and diabase	?	"
"	Upper Kaltinsk	Akineyevo	3	2197—2200	Quartz gabbro and diabase	In hanging wall	None
Extrusive rocks not drilled through	"	Varzi-Yatchi, 7	10	1854—1864	Amygdaloidal porphyrite	Yes	"
Upper Kaltasinsk	Middle Devonian	Arlan, 7	2	1940,3—1942,3	Prunoid diabase	None	Yes
Intrusion not drilled thru	Lower Serafimovsk	Staro-Petrovo, 5	33	2670—2703	Gabbro and diabase	—	None
Lower Serafimovsk	"	Serafimovka, 65	55	2587—2642	"	—	"
Intrusion not drilled thru	"	Baykibashevo, 3	18	2384—2404	Fine-grained diabase close to Staro-Petrovo paleodiorite	—	"
Lower Serafimovsk	Lower Serafimovsk	Nadezhdino, 27	166,18	2249,18—2415	Dolerite, syenite diorite, quartz gabbro and diabase	In hanging wall and floor	"
"	"	Or'yebash, 57	8	2224—2232	Dolerite	" "	"
Intrusion not drilled thru	"	Chekmagush, 5	35	2098—2133	Quartz gabbro and diabase	In hanging wall	"
"	"	Chekmagush, 77	32	2095—2127	Same	Same	"
Upper Serafimovsk	"	Serafimovka, 119	86	2656—2742	Gabbro and diabase	—	"
"	"	Staro-Petrovo, 5	5	2550—2555	Paleodiorite	—	"
Intrusion not drilled thru	Lower Valday	Kopey-Kubovo, 10	19	2141—2160	Gabbro and diabase	None	Yes
Archean	Devonian	Subkhankulovo, 5	37	1759—1796	"	"	"
Intrusion not drilled thru	"	Bakaly, 2	36	1750—1816	"	"	"
"	"	Dubrovka, 1	9	1785—1794	"	"	"

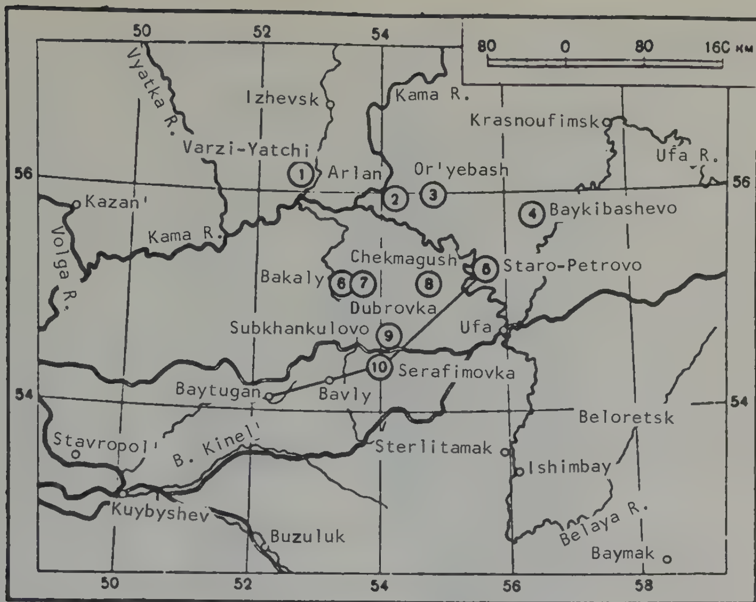

FIGURE 1. Index map of the Volga-Ural region, indicating the distribution of boreholes

1 - Varzi-Yatchi; 2 - Arlan; 3 - Novo-Or'yebash, Akineyevo, Nadezhdino; 4 - Baykibashevo; 5 - Staro-Petrovo; 6 - Bakaly; 7 - Dubrovka; 8 - Chekmagush; 9 - Subkhankulovo; 10 - Serafimovka, Kopey-Kubovo. Circles are boreholes and areas where diabase has been found; line — cross-section.

1. Olivine gabbro and diabase, dark-gray, unevenly colored. Their microscopic structure has been determined as ophitic, locally poikilolitic, with a grain size of 0.2 to 2.2 mm. Rock-forming minerals are plagioclase, monoclinic pyroxene, and olivine, with associated hornblende, biotite, K-feldspar, and quartz in micropegmatite, also titanomagnetite and apatite, and with secondary sericite, chlorite, and carbonates. The quantitative mineral composition of this rock is given in Table 2.

Plagioclase occurs in two generations: as plagioclase No. 66, in small prisms very definitely idiomorphic on pyroxene (extinction angle ⊥ PM = 36°), and corresponding to basic labradorite,[3] in composition; and as tabular plagioclase (extinction angle ⊥ PM = 30°, corresponding to labradorite No. 35-45, in composition. Plagioclase grains altered, very unevenly sericitized. The monoclinic pyroxene slightly brownish, occurring most commonly in irregular grains (35 to 45%).

Judging from its optical properties and the small optic angle, this pyroxene is poor in calcium; judging from its average refractive indices, it is poor in iron but rich in magnesium and is a magnesium-rich pigeonite-augite. Olivine, in typical sections, is mostly greatly altered (5 to 8%). Hornblende (3 to 5%) and pleochroic biotite (7 to 8%) (drab-brown to yellowish green) commonly replace pyroxene. Present among dark components are chlorite and chloritic serpentine. Titanomagnetite, whose content reaches in places 7%, occurs in strongly irregular grains, up to 0.8 mm. This rock is characterized by the presence of micropegmatite in interstices between other grains (up to 8%), with a very common micrographic structure of rectilinear outlines of quartz growths in feldspar, reminiscent of cuneiform writing. An uneven, cluster-like distribution of a dark and light-colored component is conspicuous (Figure 3); Or'yebash No. 57, thin sections Nos. 424, 424-a, b, c. Rocks from the Anikeyevo No. 24 borehole, studied by K. R. Timergazin, are of this type; according to him, they constitute an apophysis or an independent dike.

2. Picritic diabase has been studied by K. R. Timergazin [12]. They have been encountered in lower intervals of boreholes Or'yebash, Nos. 22 and 57. According to T. A Lapinskaya and F. S. Knyazeva (oral communication), chemical analyses of these rocks contain up to 24% MgO, with much olivine rich in MgO observed in thin sections.

[3]All data on plagioclase composition, obtained with flat table, have been confirmed by precision methods (Table 3), with small discrepancies.

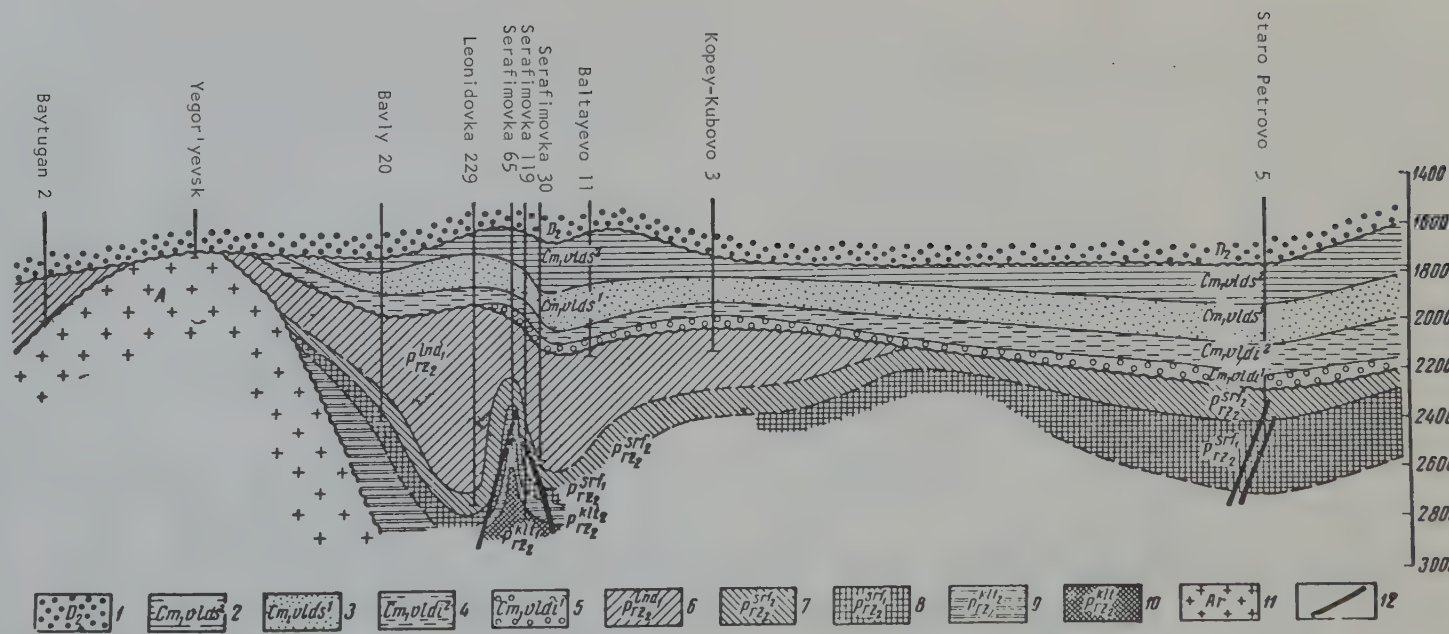

FIGURE 2. Generalized cross-section along the line Baytugan - Staro Petrovo. Compiled by Z.P. Ivanova and A.A. Klevtsova, 1958.

1 - Middle Devonian; 2 - Upper Valday Lower Cambrian metashale; 3 - Upper Valday Lower Cambrian sandstone; 4 - Upper Valday Lower Cambrian metashale; 5 - Upper Valday Lower Cambrian sandstone; 6 - lower Leonidovo beds of the Leonidovo upper Proterozoic formation; 7 - upper Serafimovka beds of the Serafimovka upper Proterozoic formation; 8 - lower Serafimovka beds of the Serafimovka upper Proterozoic formation; 9 - upper Kaltasinsk beds of the Kaltasinsk upper Proterozoic formation; 10 - lower Kaltasinsk beds of the Kaltasinsk upper Proterozoic formation; 11 - Archean; 12 - gabbro and diabase intrusions. Horizontal scale, 1:100,000; vertical scale, 1:20,000.

TABLE 2

Quantitative mineral composition of upper Proterozoic intrusives from the Volga-Ural and south Urals buried diabase formation (in volume per cent)

Age of enclosing rocks	Location and No. of borehole	Specimen No.	Depth of coring, m	Rock name	Minerals: Plagioclase	Monoclinic pyroxene	Olivine	Biotite	Hornblende	Secondary amphibole and chloritic serpentine	Titano-magnetite	Micropegmatite	Quartz	Apatite
Kaltasinsk formation	Or'yebash, 57	425	2335—2338	Olivine gabbro and diabase	36.4	36.9	1,0	—	2.7	3.3	5.2	7.6	5.3	+
Serafimovka formation	Staro-Petrovo, 5	395	2680—2700	Gabbro and diabase	56.2	27.9	—	—	—	9.6	4.2	1.2	1.6	+
	Serafimovka, 65	74	2616	"	46.2	38.5	—	—	4.9	2.4	8.0	—	—	+
	Nadezhdino, 27	536-a	2245.18 2252.48	Dolerite	63.0	—	—	7.5	—	18.8	7.2	1.8	8.8	+
	"	537	2269—2274	Syenite or diorite	33.1	—	—	0.2	18.3	—	9.6	30.2	8.1	0.5
Inzersk formation of south Urals — correlative of Lower Serafimovka beds	Inzer	63	Outcrop	Gabbro and diabase	51.7	27.4	—	—	4.8	4.8	5.2	4.7	1.4	+
	"	59	"	Dolerite	57.5	36.4	—	—	—	1.5	—	4.6	—	—

FIGURE 3. Gabbro and diabase; rock segment enriched in dark components.

Or'yebash No. 57; thin section No. 425; depth, 2324 to 2395 m; magnification, 65 x; crossed Nicols

3. Quartz gabbro and diabase have been identified by K. R. Timergazin in upper intervals of boreholes Or'yebash, Nos. 22 and 14.

4. Amygdaloidal porphyrite (Varzi-Yatchi borehole No. 7). According to K. I. Lomot' [9], there are two varieties of these rocks: a more basic and a more acid. One of the authors had the opportunity to study the more basic varieties.

a) The more basic variety of amygdaloidal porphyrite (Figure 4), whose structure was determined with the microscope, is marked by the presence of rare incrustations of monoclinic pyroxene and plagioclase, and of coarse amygdules, up to 3.5 mm (10%).

The groundmass with an intersertal texture is made up by laths of plagioclase, strongly altered pyroxene grains, chlorite, and ore minerals. The amygdules are filled with calcite and partly with clorite and zeolites (thin slides 851/54 and 851/54-a).

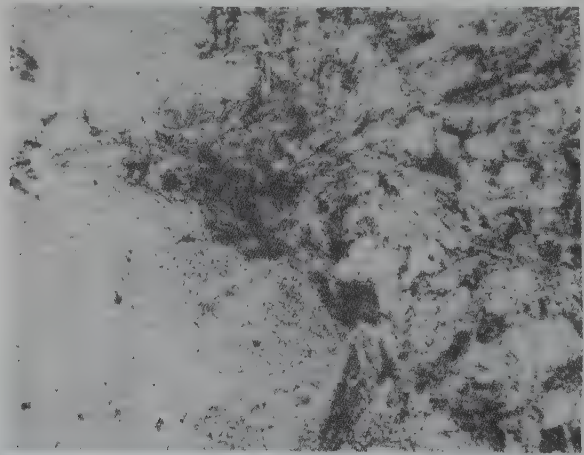

FIGURE 4. Amygdaloidal porphyrite; amygdules filled with chlorite and zeolites.

Varzi-Yatchi, No. 7; thin section No. 851/54; depth, 1855 to 1859 m; magnification, 65 x; transmitted light

The second variety of amygdaloidal por-ite, according to K.I. Lomot', is more with quartz in the groundmass but without xene. This variety was chemically analysed e I.M. Gubkin Petroleum Institute, Moscow. pears that the sizable content of potassium e (3.72%) in this rock is due to the presence otassium in the groundmass.

THE SERAFIMOVKA FORMATION

Lower Serafimovka Beds

gneous rocks are most common in the lower afimovsk formations. As seen from Table ey are very diversified.

. Gabbro and diabase are the most common s (lower interval of borehole Staro-Petrovo 5; Baykebashevo, No. 3; Serafimovka, No. containing different varieties. There is a lished description of gabbro and diabase n the Staro-Petrovo No. 5 borehole, by V.P. renskiy and I.M. Varentsov. We, too, have cribed the rocks from that borehole.

a) Gabbro and diabase from lower intervals he Staro Petrovo borehole are coarse-ined, dark-gray, with slickensides. Their itic texture is noticeable under the micro-pe (Figure 5), with grains of 0.5 to 2 mm. k-forming minerals are plagioclase and noclinic pyroxene, with associated horn-nde, biotite, K-feldspar, and quartz (in ropegmatite), and secondary chloritic ser-tine, chlorite, sericite, and carbonates. gioclase is of two generations: 1) in prisms, rywhere idiomorphic on pyroxenes (ex-ction angle ⊥ PM = 34°), corresponding to basic labradorite in composition; 2) in tabular grains (extinction angle ⊥ PM = 27°), corresponding to basic andesine No. 48.

Plagioclases are commonly zoned. Monoclinic pyroxene (35 to 40%) occurs mostly in irregular slightly greenish grains. Judging from its optical constants, a small axial angle, this pyroxene is poor in calcium; judging from its refractive indices, it is low in iron and high in magnesium and is a magnesium-rich pigeonite-augite. The outlines of grains filled with secondary minerals, possibly formed on olivine, are present in the rock.

Present about the pyroxene grains and in interstices between them is a common drab-green olivine whose optic constants, according to I.M. Varentsov [4], are as follows: $2V = 86°$; $c\gamma = 10°$; $\gamma - \alpha = 0.021$; pleochroism yellowish-brown along γ and greenish-yellow along α.

Biotite occurs in tablets, with color and pleochroism varying from red-brown along γ to light-yellow along α. Quartz and K-feldspar fill interstices between the grains, as micropegmatite, but in a "nascent state", amounting to only 2 to 4%. Titanomagnetite is common among accessory minerals (2 to 6%). The rock also contains apatite, often in fine aciculae. For the qualitative mineral composition of this rock, see Table 2 (thin sections 395, 395-a, b, c).

b) Fine-grained diabase (Serafimovka No. 65 borehole), very dark to almost black. Under the microscope, its texture is gabbroic ophitic (Figure 6), with grains ranging from 0.2 to 1.0 mm. Rock-forming minerals are plagioclase and monoclinic pyroxene; subordinate titanomagnetite, apatite, biotite, amphibole, and quartz;

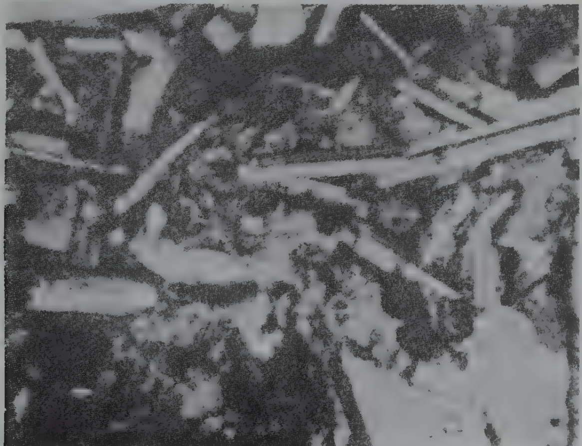

FIGURE 5. Gabbro and diabase.

Staro-Petrovo borehole No. 6; thin section No. 395; depth, 2670 to 2703 m; magnification, 65 x; crossed nicols

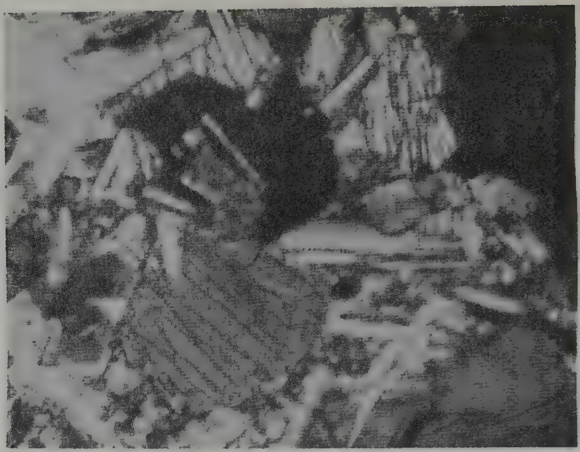

FIGURE 6. Gabbro and diabase.

Serafimovka borehole No. 65; thin section No. 74; depth, 2616 m; magnification, 65 x; crossed nicols

with secondary chloritic serpentine and sericite. Plagioclase (40 to 50%) occurs in prismatic and tabular grains. In the prismatic variety, plagioclase No. 64, the extinction angle ⊥ PM = 34°; in the tabular ⊥ PM = 28°, with the composition corresponding to that of acid labradorite. Pyroxene commonly occurs in irregular, less commonly regular grains (30 to 40%); it is colorless. The rock contains rare inclusions of biotite (2 to 5%) and hornblende (2 to 5%), usually about the pyroxene. Micropegmatite is missing. The sizable (20%) accumulations of chloritic serpentines probably replace the primary mineral. Grains of titanomagnetite (2 to 5%) have been observed. The qualitative mineral composition is given in Table 2 (thin sections 75 and 75-a, b).

2. Dolerite and paleodolerite occur in upper intervals of the section: borehole Nadezhdino, No. 27; in the upper intrusion, in the Or'yebash No. 57; and in the Baykibashevo, No. 3.

a) Dolerite from the Nadezhdino borehole No. 27 is dark, tough, fine-grained rocks, with the microscope revealing their doleritic texture changing to radial (Figure 7). The grain size is 0.1 to 0.8 mm[4] principal minerals are plagioclase and a dark altered component, apparently monoclinic pyroxene and biotite; accessory quartz, titanomagnetite, K-feldspar, and secondary amphibole and chloritic serpentine. The main rock component is plagioclase in fine prisms, accounting for about 60% of the total; its extinction angle ⊥ PM = 33°; in composition, it corresponds to labradorite No. 63. Its radial structure is due to the arrangement of plagioclase prisms. Pyroxene has been replaced by amphibole and chloritic serpentine (20%). There is some fresh biotite with pleochroism and color varying from drab-brown to light yellow. Quartz (7%) is present in interstices between grains, along with occasional K-feldspar.

Micropegmatite is missing. Titanomagnetite is present in considerable amounts (6%). For the qualitative mineral composition, see Table 2 (thin sections 536 and 536-a).

b) Paleodolerite with a variolitic (?) texture, from upper intervals of the Or'yebash No. 58 borehole, have been studied in detail by T. A. Lapinskaya and V. S. Knyazev (personal communication).

c) Paleodiorite. K. R. Timergazin encountered fine-grained basic rocks in the Baykibashevo borehole No. 3, identical with paleodiorite from the Staro Petrovo borehole No. 5, according to his data. This paleodiorite was studied by V. P. Florensov and I. M. Varentsov; in analogy with the Staro-Petrovo borehole, we retain the same name for the Baykibashevo borehole rocks.

3. Syenite-diorite is by itself among upper Proterozoic intrusives of the Volga-Ural region; it occurs in upper intervals of the Nadezhdino borehole No. 27. In chemical composition, this syenite-diorite is quite different from gabbro diabase. However, this rock is closely related, genetically, to other gabbro and diabase rocks of the Volga-Ural region, but hornblende occurs

[4]According to M. A. Favorskaya, who kindly looked over the Nadezhdino dolerite thin sections, it is rather a hybrid rock.

FIGURE 7. Syenite-diorite; zoned plagioclase surrounded by micropegmatite.

Nadezhdino borehole No. 27; thin section No. 537; depth, 2269 to 2274 m; magnification, 65 x; crossed nicols

it instead of pyroxene (or pyroxene fringed y hornblende), and its micropegmatite content eaches 30% in places. This syenite-diorite is ark, pink-gray, micropegmatitic under the icroscope, with grains of 0.2 to 2.0 mm. Its ock-forming minerals are plagioclase, quartz, -feldspar, hornblende, and biotite, with subrdinate titanomagnetite and apatite, and secndary chlorite, sericite, and carbonates. Plaioclase occurs in tabular zoned grains, its omposition varying from zone to zone, from andesine to acid labradorite (Nos. 40-55); the extinction angle ⊥ PM ranges from 22 to 31°. The outer plagioclase zone (Figure 7) has been albitized. Hornblende occurs in idiomorphic, less commonly irregular grains, or as inclusions in plagioclases. Present are biotite scales whose color and pleochroism vary from drab-brown along γ to light-yellow along α. Present amond dark components are bizarre grains of titanomagnetite, up to 0.4 mm (5 to 8%).

FIGURE 8. Contact phenomena in the intrusion floor. Metashale with inclusions of chiastolite.

Nadezhdino borehole No. 27; thin section No. 538; depth, 2440 to 2445 m; magnification, 65 x; crossed nicols

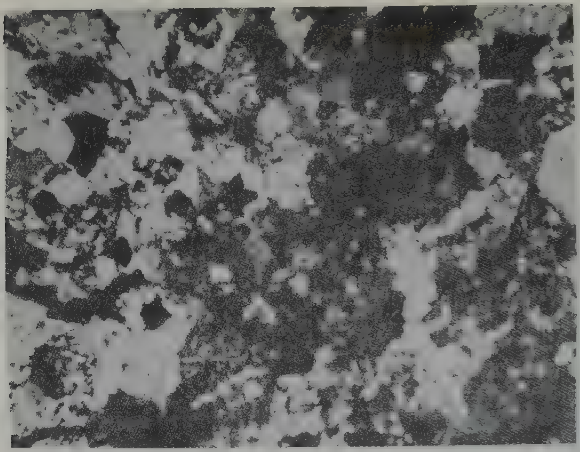

FIGURE 9. Granophyre in contact with the enclosing rock in hanging wall of the intrusion.

Nadezhdino borehole No. 27; thin section No. 535; depth, 2240.18 to 2252.18 m; magnification, 65 x; crossed nicols

Also present are long and narrow prisms of apatite (1 to 2%). Interstices between grains are filled by K-feldspar with angular growths of quartz, reminiscent of cuneiform writing (25 to 35%). Quartz (6 to 8%) also occurs in the free state (thin sections 537 and 537-a, b, c).

A chemical analysis of this rock is given below. The silica content here is almost 56%. The qualitative mineral composition of syenite-diorite is given in Table 2.

Upper Serafimovka Beds

Rocks of the diabase formation are comparatively rare in upper Serafimovka beds. They have been penetrated in borehole Serafimovka No. 119, upper intervals of the Staro Petrovo No. 5, and the Chekmagush No. 5.

We turn now to the description of rock types.

1. Quartz gabbro-diorites, described by L. D. Ozhigova (unpublished work) from the central part of the intrusion, in the Serafimovka No. 119. Their structure has been determined microscopically as that of gabbro and diabase, with a grain size of 0. 7 to 3. 0 mm. Principal rock-forming minerals are plagioclase and monoclinic pyroxene. The plagioclase is of two generations (40 to 60%): in regular prisms and in less regular tabular grains (second generation); in composition, it is labradorite No. 55-60. The monoclinic pyroxene is xenomorphic, less commonly idiomorphic with relation to other minerals, light brown, with an extinction angle $c\gamma = 43^\circ$ (25 to 35%). There is titanomagnetite with grains of 0. 5 to 1. 5 mm (5 to 10%). The constant presence of micropegmatite (up to 10%) and quartz is typical. Some apatite occurs in grains of 0. 1 to 1. 5 mm (1%).

2. Quartz diabase from the upper and lower parts of the intrusion in the Serafimovka No. 119 are very similar, except that in the upper part they have been considerably altered and carry aphanitic varieties with grains 0. 3 - 0. 6 mm at an ordinary size of 0. 3 - 1. 3 mm. The microscope reveals their ophitic and poikilophitic texture, with a doleritic texture in the upper part.[5] The rock is 50% plagioclase, labradorite (No. 50-55), of two generations: fine, idiomorphic prismatic grains and coarser tabular ones. In the upper part, plagioclase has been strongly altered. Quartz and K-feldspar (replaced by kaolinite, on top) are present. A greenish monoclinic pyroxene has been observed in xenomorphic grains (30%); on top, it has been strongly altered and replaced by orange-brown to greenish brown mica. There are grains of titanomagnetite and magnetite and isolated grains of apatite.

3. Quartz diabase with 25% micropegmatite has been penetrated in the Chekmagush borehole No. 5, and described by K. R. Timergazin [12].

4. Paleodiorite has been described by V. P. Florenskiy and I. M. Varentsov [14] from an upper interval of the Staro-Petrovo borehole. It

[5]It is possible that the altered fine-grained diabase with a dolerite structure is identical to dolerite from upper intervals of many boreholes.

chiefly a dark gray, fine-grained rock, mostly th a doleritic structure. Its principal miners are pyroxene and plagioclase. The plagioase is of two generations; it accounts for about % of the total. There are coarse zoned tabur grains with ranging in composition from bradorite to bytownite (No. 60-75). The bulk the rock consists of fine lath-like (leist) agioclase grains (No. 45-55). The pyroxene is been destroyed, with only its pseudomorphs emaining. These rocks have been strongly tered, with calcite the most prominent among econdary minerals (30 to 40%); hydroxides of on, and leucoxene are present.

To convey an idea of the Volga-Ural buried abase formation as a whole, Table 1 contains rief information on the igneous rocks resting n the crystalline basement and overlain by the evonian and Upper Cambrian sequences. This ble shows that igneous rocks in boreholes ubkhankulovo No. 5, Kopey-Kubovo No. 10, ubrovka No. 1, and Bakaly No. 2, Aznakayevo, nd Suleyevo in Tatariya, have been strongly ltered by weathering.

MINERALOGY OF THE VOLGA-URAL BURIED DIABASE REGION

Principal rock-forming minerals of the uried diabase formation are plagioclase and nonoclinic pyroxene, with olivine present in ome varieties. In most gabbro and diabase, lagioclase occurs in two generations. Plagiolase in fine prisms, strongly idiomorphic on yroxene grains, corresponds to labradorite in omposition (Table 3). This is not always the ase with coarser tabular or irregular grains which seem to be acid labradorite or basic ndesine in composition.

Rare and strongly altered coarse grains of lagioclase are present in the dolerite, while he groundmass is made up of fine laths of abradorite. We have not discovered any deviations from the standard curves for determining plagioclase: varieties under study were epresented by common low-temperature plagioclases of an intrusive origin.

Monoclinic pyroxene of gabbro and diabase nas usually been observed in irregular, rarely n regular grains of a second generation; the nonoclinic pyroxene is idiomorphic on plagiolase, and is pale-green to brownish. Simple wins are present in some varieties. Table 3 gives the optical constants for monoclinic pyroxene from various rocks. Conspicuous is the comparatively low value for the optic angle in yroxenes peculiar to hypabyssal and intrusive ocks [1]. In addition, the low value of 2 V ndicates that these pyroxenes are poor in calcium oxide and rich in oxides of magnesium and iron. The relatively low refractive indices suggest, however, an equally low iron content, so that, judging from the optical constants, monoclinic pyroxene may be magnesium-rich pigeonite-augite. On A. P. Lebedev's diagram [8], "Optical properties and molecular composition of clinopyroxenites from intrusive traprocks of the Tunguska Basin", our pyroxenes fall in a group of pyroxenes characteristic of normal poikilophitic and other diabases, i. e., pigeonite-augite with 2 V = + 40 to 50°, with refractive indices of 1. 705 to 1. 720 and $c\gamma = 40°$.

Amphibole in idiomorphic grains has been observed in considerable amounts only in the Nadezhdino borehole No. 27; in other boreholes, it occurs mostly in fringes on pyroxene grains. As established from its optical constants, it is a common hornblende.

Olivine, which we discovered in the Kaltasinsk beds of the Or'yebash No. 57 borehole, has not been studied for its alterations. According to T. A. Lapinskaya and V. S. Knyazev (personal communication), who have studied optical constants for the Or'yebash olivine, it is a magnesium-rich chrysolite.

We have not observed any rhombic pyroxene. According to K. R. Timergazin [12], it occurs in lower intervals of the Or'yebash boreholes.

Biotite occurs most often in dolerite, as indicated in Table 3; its color and pleochroism vary from drab-brown to light-yellow. It occurs occasionally as a fringe on pyroxene grains.

Quartz has been observed in almost all rocks, mostly in quite irregular grains, chiefly in interstices between the grains of other minerals, also in graphically regular growths in K-feldspar.

K-feldspar in micropegmatite occurs in all rocks except for the most basic intrusions of Kaltasinsk age.

Titanomagnetite in very irregular, webbed bizarre grains is present in all rocks; it crystallized after apatite and simultaneously with plagioclase and pyroxene.

Apatite is the most common accessory mineral in rocks of the diabase formation. It is especially abundant in the Nadezhdino syenite-diorite (see Table 3) and occurs in finest aciculae, 0. 01 to 0. 1 x 1. 0 mm; the same is true for the Chekmagush borehole No. 5 (K. R. Timergazin's data, [12]).

Common among secondary minerals is chloritic serpentine (bowlingite, according to the staff of the I. M. Gubkin Petroleum Institute, Moscow) and a yellowish-green chlorite, with a gray interference color. These minerals

TABLE 3

Optical constants of rock-forming minerals from upper Proterozoic intrusives in the Volga-Ural and South Urals Diabase Formation

Age of enclosing rocks	Location and borehole	Sample No.	Depth of sampling in m.	Rock	Dark	
					γ	α
Katasinsk formation	Or'yebash, 57	425	2335—	Olivine gabbro and diabase		
		455-a	2338		1.706±0.004	1684±0.002
Serafimovka formation	Staro-Petrovo[1]	395 395-a	2680—2700	Gabbro and diabase	1.704±0.002 1.712±0.002	1700±0.02
	Sterafi-movka,65	74	2616	Same	1.712±0.002	1688±0.002
	Nadezzdino, 27	536	2245.18—2252.48	Dolerite		
	Same	537	2269—2274	Syenite-diorite	1680±0.002 1684±0.002	1.664±0.002 1.672±0.002
Izer formation, correlative with lower Serafimovka beds	Village of Izer South Urals	59	Not det'd.	Dolerite	1.708±0.002 1.712±0.002	1.696±0.002 1.700±0.002
		63		Gabbro and diabase	1.712±0.002 1.716±0.002	1.700±0.002

[1] Optical constants for the Staro-Petrovo plagioclase, after V.P. Florenskiy, T.A. Lapinskaya,

[2] Pleochroism in hornblende is drab-green along γ; green along β; and yellow-green along α.

replace pyroxene and olivine, while plagioclase is replaced in places by chlorite. An amphibole of the actinolite-tremolite group also occurs on dark minerals.

Calcite is often developed on plagioclase in the dolerite. Fine prismatic plagioclase grains usually appear fresher in diabase, while the coarse tabular ones have been more or less sericitized. All rocks of the diabase formation (as well as those of the crystalline basement) are cut by numerous vertical veins, mostly of hematite, chlorite, carbonates, the silica group minerals, etc. According to K. R. Timergazin [12] and M. A. Garris [2], these veins occur not only in diabase but in all enclosing and overlying formations, through the Frasnian.

CHEMICAL FEATURES OF THE VOLGA-URAL BURIED DIABASE FORMATION

The igneous rocks described above were chemically analysed in the I. M. Gubkin Petroleum Institute, Moscow, and recently in the All-Union Scientific Research Institute for Petroleum Geologic Exploration (V.N.I.I.G.N.I.). Table 3 presents chemical analyses of igneous rocks from the Volga-Ural region and ancient formations in the Urals. Analyses of the Varzi-Yatchi porphyrite and the Staro-Petrovo paleodiorite are omitted, because these rocks have been greatly altered. The analyses are listed by their age and basicity.

According to A. N. Zavaritskiy [4], "the

Table 3 (cont'd)

minerals			Orientation of indicatrix				Plagioclses		
2V (deg.)	c γ (deg.)	Name	Dγ	Dβ	Dα	2V (deg.)	Twinning rule	No.	Name
+50	+41	Pigeonite-augite	59	72	38	+83	Carlsbad	67	Basic labradorite
+52	38		59	60	41	65			Acid labradorite
+46	44	Pigeonite-augite	72	30	67	+78	Albite	67	Basic labradorite
+45	43		77	38	58	+65	Carlsbad	60	Labradorite
+47	44		71	40	52	+87	"	45	Basic labradorite
			65	51	50	+69	"	48	Basic andesine
+48	—	Same	59	71	37	+84	"	67	Basic labradorite
+50	42	–	—	—	—	+82	"	—	" "
+49	—								
			33	60	78	+70	Albite	52	Acid labradorite
—76	23	Common horn-blende[2]	28	63	83	+86	Peri-cline	43	Andesine
—79	21		27	64	83	+82		43	"
+43	42	Pigeonite-augite	38	61	69	+80	Albite	66	Basic labradorite
+46	—								
+46	—								
+46	42	Same		Coarse	grained				
+44	—	–	39	65	65	+81	Pericline	63	Labradorite
+44	—	–	36	65	65	+82	"	65	Basic labradorite

nd V.S. Knyazev (15).

sual order in an intrusion is that of rising cidity", which has been observed on the whole vith some deviations) in the Volga-Ural region. he most basic rocks are olivine diabases nplaced the deepest in the oldest upper Kalta-nsk formations of the Or'yebash boreholes here they carry 44 to 46% SiO_2. The most out-tanding chemical feature of these rocks is their xceptionally high magnesium oxide content (up 24%). Quartz diabases have been penetrated oove the olivine rocks, chiefly in lower Sera-movka horizons. In upper intervals of some oreholes, lower and upper Serafimovka rocks arry syenite-diorite (Nadezhdino No. 27) and ssociated rocks (Chekmagush, No. 5) with % SiO_2. Higher up, this order of intrusions broken, and more basic rocks, e.g., dolerite (52% SiO_2), lie above the syenite-diorite, in almost all boreholes.

Because of inadequate data, the average composition of basic rocks in the area has not been calculated. Despite the difference in composition between the most basic and most acid varieties, a comparative stability and consistency has been noted in the content of oxides of magnesium, iron, calcium, and sodium, from common gabbro and diabase, in Bashkiriya and Tatariya as well as in the south Urals.

One of the geochemical features of all igneous rocks of the Volga-Ural region and the Urals is their higher magnesium content, usually about 7%, in contrast with 5.7% for the Siberian

traprocks [8]. We have already mentioned the MgO content of up to 24% in most acid varieties. Another characteristic feature is the variable but mostly low calcium oxide content, usually 7 to 8%, in contrast to 10 or 11%, common for the platform type diabase formations [21].

CONTACT PHENOMENA

Contact phenomena associated with basic rocks are usually inconspicuous, because a basic magma is poor in volatiles,[6] and its temperature during the intrusion is comparatively low. According to the most recent data on the coking of coals cut by dolerites, the temperature here was not lower than 570°C. In boreholes, contact phenomena are difficult to identify because of the lack of cores.

Among contact phenomena is the change in granulation along the edge of an intrusion, as well represented in the Serafimovka No. 119 and Nadezhdino, No. 27 boreholes. In the Serafimovka No. 119, medium- to coarse-grained rocks have been observed at the center of the intrusive body; toward the sedimentary rocks, they become fine- to very fine-grained, in places almost aphanitic. In addition, gabbro and diabase of the central part grade completely to diabase, toward the periphery of the intrusive body. The same zoned structure of thick dikes has been noted by B. A. Yudin for the Kola Peninsula basic rocks [18]; by A. P. Lebedev for traprock [8]; and by other authors.

The appearance of micropegmatite segments, not found deeper or away from the contact with enclosing rocks frequently carrying arkosic sandstone, is possibly associated with endocontact processes also. However, this is difficult to assess, because of the scarcity of data. The appearance of fresh biotite in thin dolerites also seems to be an example of endocontact processes.

Exocontact phenomena in the hanging wall and floor of the Volga-Ural intrusions suggest that what has been observed here is not evidence of extrusive activity but rather typical contact phenomena related to the intrusion of magma into sedimentary rocks.

Because the opportunity to study the effect of intrusive rocks in the sedimentary in boreholes is rare, we shall take up in more detail the description of those drilled intervals which show direct contacts between these rocks.

Present in the hanging wall of borehole Nadezhdino, No. 27, at 2440 to 2445 m, are alternating tough, almost schistose, metashale, siltstone, and dolomite. In reflected light, the entire sequence appears to be unevenly colored red. A high magnification reveals that this is due to a local accumulation of fine spherules or grains of hematite of about 0.01 mm in diameter. The non-colored segments of metashale, consisting of a nearly isotropic groundmass[7] with a refractive index of 1.543 ± 0.003 mm and carrying muscovite scales, contain coarse (0.2 to 0.5 mm) rectangular formations with a distinct hour-glass structure emphasized by the distribution of fine hematite grains and carbonaceous particles (Figure 8). They appear to be the "skeletons" of chiastolite or otterlite. Both these minerals are typically contact ones, often occurring in metamorphic shale. Which one of the two minerals has been present is difficult to decide, because these "skeletons" are now filled by a fine-scaled birefringent argillaceous mineral with a gray to yellow interference color. It appears that chiastolite or otterlite were unstable in a physiochemical environment different from that of their origin.

Occurring at 2249.19 to 2252.48 m, in the hanging wall of the intrusion is a lavender-black metashale, altered as an effect of the intrusion. Seen under the microscope, its groundmass consists of hydromicaseous (?) scales with a yellow interference coloring (isolated scales are red and blue).

Biotite scales, whose color and pleochroism range from brown-yellow to colorless, are present. The rock contains bands enriched in spherical bodies (accasionally rectangular), alternating with bands free of them. The nature of these bodies is not yet clear. Their diameter ranges from 0.02 to 0.1 mm. Still finer spherules or grains of iron hydroxide are disseminated within these bodies. It was found in a thin section from the immediate intrusion-shale contact that 80% of the latter was the metashale described above, and 20% granophyre of K-feldspar with angular quartz growths (Figure 9).

The same rounded bodies as those in the Nadezhdina No. 27, and under the same conditions, have been found in the hanging wall of the intrusion, in the Or'yebash borehole No. 57. Dolomite of the same interval carries numerous accumulations of pale-green chlorite scales (chloritization of rocks at the intrusion contact). In the same place, round and rectangular formations, 0.5 to 1.0 mm, occur in fine-grained dolomite. Their origin is not clear. It is possible that they, too, are contact phenomena,

[6] A. P. Lebedev's observation on the high content of fluids in a traprock magma. The same thing has been noted by F. Walker and A. Pol'dervaart for South African diabases.

[7] A clay mineral, possibly halloysite.

ypothetical fossils whose traces have been erved in carbonate rocks of other boreholes.

n addition, a feldspathization of rocks should noted, not necessarily of those in immediate act with the intrusions but enclosing them. s possible that this is an effect of the intru- 1. It is more probable, however, that these ly-formed feldspars are the result of a po- sium and sodium metamorphism in the crys- ine basement rocks which has also affected sedimentary mantle.

A CORRELATION OF THE VOLGA-URAL URIED DIABASE FORMATION WITH THE URALS AND OTHER REGIONS, AND ABSOLUTE-AGE DETERMINATIONS

According to K. R. Timergazin [12], "in the stern part of the west slope of the Bashkirian als, diabase rocks cut the entire sedimentary tion, through the Min'yarsk formation, and missing in the overlying Ashinsk Cambrian mation". Diabase rocks occur in dikes, m 0.5 to several tens of meters thick. K. R. nergazin and the authors correlated the Min'- sk formation with upper Serafimovka beds. mentioned previously, diabases do not occur ove the latter. The resemblance between the alian gabbro and diabase, and dolerite, and nilar rocks from the upper part of the lower vly (Bavlinsk) formation (see Tables 2 and 4) very conspicuous.

A parallel study of optical constants was done the rock-forming minerals in basic rocks of e Inzer, Kaltasinsk, and Serafimovka forma- ons. Worthy of attention is the fact that optical nstants, the refractive indices, optic angles, c. are identical for monoclinic pyroxenes from e Inzer gabbro and diabase and similar rocks om the lower part of the Bavly formation. All ese geologic and petrographic features suggest e same age for these igneous rocks and that ey belong to the same igneous province. Of terest is the attempt of A. I. Tugarinov and . A. Garris to determine the absolute age of icropegmatites from the diabase formation. ccording to A. I. Tugarinov (personal com- unication) of the V. I. Vernadskiy Institute of eochemistry and Analytic Chemistry, the age syenite-diorite from the Nadezhdino, No. 27, orehole is 1300 million years. According to reliminary data of M. A. Garris (Laboratory of e Mining and Geological Institute, Bashkirian ffiliate A. S. U. S. S. R.), as cited by K. R. imergazin [12], the absolute age, determined the K-Ar method, is 1010 million years, for e Chekmagush, No. 5; and 1140 million years r the Staro-Petrovo, No. 5 (lower intrusion).

According to the latest tabulation by N. P. emenenko [10], the Ovruch quartzites of the kraine are 1400 million years old; the Koro- en' igneous complex, 1150 to 1250 million years old; and the upper Proterozoic alkalic complex, 500 to 900 million years.

Thus, igneous rocks under study are upper Proterozoic, which corroborates on the whole our data on the age of the lower Bavly formation. On the other hand, in his study of glauconite from ancient formations of the Urals, G. A. Kazakov [6] cites a figure of 865 million years for the Inzer formation, and 680 to 690 million years for the lower part of the Serdobsk series (Kaltasinsk formation), so that the determinations made on glauconite do not agree with those made on igneous rocks rich in feldspar and biotite; according to the N. P. Semenenko tabulation, however, their age, too, is upper Proterozoic.

CONCLUSIONS

1. The buried diabase formation of the Volga-Ural region is a platform type formation and has many features in common with other typical platform formations, such as the Siberian traprocks [8]; dolerites of Karru, South Africa [21]; and the Madagascar diabases [19].

2. Buried at depths of about 2000 to 3000 m, these intrusive rocks are developed throughout Bashkiriya, Tatariya, Permskaya Oblast', and Udmurtiya. These rocks are 3.0 to 165 m thick. In analogy with basic rocks in the western part of the west slope of the Bashkirian Urals (to which they are similar chemically, mineralogically, and in age), their predominant form of occurrence is dikes.

3. The upper age limit for these intrusive rocks is established by their absence in the Cambrian of the Volga-Ural region; nor have they been observed in the pre-Ordovician Ashinsk formation of the Urals. It appears that the magmatic intrusion (related to rifts in the basement) in the Kaltasinsk and Serafimovka formations occurred between the late Proterozoic and the Cambrian; this is not in contradiction to the absolute-age data and it agrees with our conclusions on post-Proterozoic tectonic movements. All igneous activity in the Volga-Ural region occurred only at that time; it took place at a single stage and is characterized by close genetic ties and a great similarity in petrographic and chemical composition of the rocks formed. Those igneous rocks which rest on the crystalline basement and are overlain by younger formations have a weathered zone pointing to their early origin, prior to the deposition of the overlying rocks.

4. All such rocks are hypabyssal; an extrusive origin is out of the question because of the contact phenomena in the hanging walls of the intrusions.

5. The magmatic intrusion was very intensive. The magma, ascending along wide rifts, was intruded along the weakened zones of

TABLE 4

Chemical analyses of upper Proterozoic intrusives in the Volga-Ural region of Tataria and in ancient formations of the Urals (volume per cent)

Components	Or'yebash 57[1]	Serafimovka, 65	Inzer, Urals	Inzer, Urals	Staro-Petrovo, 5[1]	Nadezhdino, 27	Staro-Petrovo, 5[1]	Tatariya, Suleyevo[1]	Nadezhino 27
	Sample Nos.								
	22-2	74	63	59	5-20	536	5-14	37,1	537
	Sampling depth, m								
	2335–2338	2616	Not det'd.	Not det'd.	2680–2700	2249,18–2252,48	2680–2700	—	2269–2274
	Rock names								
	Olivine, gabbro and diabase	Gabbro and diabase	Gabbro and diabase	Dolerite	Gabbro and diabase	Biotite, dolerite	Gabbro and diabase	Gabbro and diabase	Syenite-diorite
SiO_2	46.0	48.13	49.11	49.11	52.10	52.10	53.22	53.28	55.10
TiO_2	0.64	2.01	0.60	0.60	1.75	0.84	1.32	1.20	2.05
Al_2O_3	8.30	14.43	17.77	19.24	13.67	16.67	13.50	14.00	13.10
Fe_2O_3	4.03	4.28	3.64	2.09	6.54	4.33	4.16	7.58	4.08
FeO	7.35	7.62	9.41	8.74	7.25	3.56	7.90	6.45	8.77
MnO	0.09	0.18	0.05	0.03	0.02	0.10	0.02	0.02	0.20
MgO	23.30	6.92	6.43	7.23	7.17	7.58	6.67	5.30	3.29
CaO	7.15	9.91	9.83	10.75	6.85	6.85	8.60	7.76	3.94
Na_2O	0.81	2.38	2.02	1.92	2.48	2.66	1.85	2.82	2.81
K_2O	0.60	0.83	0.46	0.16	0.21	0.96	0.20	0.40	2.97
P_2O_5	0.08	0.25	0.10	0.05	0.82	Not det'd.	0.61	0.80	0.70
SO_3	None	Not det'd.	Not det'd.	0.05	None	"	None	None	Not det'd.
S	"	"	Not det'd.	Not det'd.	"	"	"	—	"
Cl	Traces	"	"	"	Traces	"	Traces	Traces	"
Losses in heating	2.40	1.60	1.06	0.64	1.10	2.77	1.75	1.15	2.10
Total	100.75	100.23	100.48	100.61	99.96	100.23	99.88	100.77	99.85
Hygroscopy	None	1.40	0.69	0.64	1.23	1.87	None	0.38	0.8
Analyst	B. V. Bal'shina	I. V. Nikitiha	M. G. Shapovalova	M. G. Shapovalova	B. V. Bal'shina	N. V. Nikitina	B. V. Bal'shina	B. V. Bal'shina	N. V. Nikitina

[1]Chemical analyses performed in the Gubkin Petroleum Institute, Moscow (1954-1955).

dimentary rocks and hollows formed in the ck by compaction, on one hand, and in the similation of sedimentary rocks, on the other.

6. Common gabbro and diabase are derivaes of a basic magma, peculiar in its chemisy, rich in magnesium and poor in calcium, as came up from greater depths. All other hyid forms appear to have originated from a hyidized basic magma, originating by a deep similation of sedimentary and other enclosing cks.

7. The genesis of the Volga-Urals diabase rmation was accomplished first by a gravity fferentiation, somewhat complicated by the ssimilation phenomena, because the lower parts the intrusions (Or'yebash, Nos. 22 and 57) are arked by a considerable amount of olivine, with artz diabase missing. Rocks enriched in artz and micropegmatite occur in the middle art and toward the top, with a hybrid syeniteorite appearing at Nadezhdino, in that direcon. Thus the "usual order of the intrusions is eir rising acidity", apparently connected with change in the basic magma, in its assimilation f enclosing rocks, rather than with differentiaon [13]. In upper parts, this order is broken, ith dolerite more basic than syenite-diorite ppearing in upper intervals of many boreholes. he magma, passing to a more shallow zone, hanged in equilibrium with the new conditions; owever, where its peripheral part cooled raidly, tempering took place instead of the other hanges. In other words, the composition and ature of these rocks reflect the state of the agma at great depths.

8. The contact phenomena, related to the inrusions and considered in detail in this work, must be taken into account in studying the reservoir properties of rocks; in any event, the etrimental effect of such phenomena must be considered.

9. Oil showings in the upper Proterozoic of he Volga-Ural region do not seem to be directly related to the appearance of intrusions. However, changes in physiochemical conditions, and he local heating up to no less than 570° must be aken into account in studying oil prospects of his area.

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TRANSPORTATION AND ACCUMULATION OF IRON AND ALUMINUM IN VOLCANIC PROVINCES OF THE PACIFIC[1]

by

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Intensive transportation of a number of elements, especially iron and aluminum, takes place in cent volcanic provinces. These metals are leached out of extrusive rocks by thermal waters rmed as a result of the solution of volcanic gases in ground water. Subsequent migration of iron d aluminum is controlled by the amount of precipitation which dilutes the thermal waters. Under vorable conditions, large amounts of dissolved aluminum are carried out to sea where it is pre- pitated as aluminum hydroxide suspension and deposited on near-by coral islands.

* * * * *

The conditions of formation of acid thermal aters in provinces of recent volcanism, as well the decomposition processes in their carrier cks and the leaching of many elements, have en studied in detail [12, 14, 17]. The essence these phenomena is that meteoric waters cir- lating in volcanic rocks dissolve volcanic ses (HCl, H_2S, SO_2, $B(OH)_3$, CO_2, etc.), and come a mixture of strong acids; reacting with e enclosing rocks, they are enriched in alka- es, alkaline earths, as well as in iron and uminum which go into solution almost com- etely, in the process of acid dissociation of trusive rocks.

The scope of this process and the fate of dis- lved elements were not clear, until recently. was supposed that rapid dilution and neutrali- ation of thermal waters by meteoric waters lead nly to a dispersion of these elements. However, ecent quantitative analysis of thermal streams f the Kurile Islands has shown the amazingly rge extent of the leaching process, chiefly of on and aluminum, and of their transportation marine basins. A single small thermal tream, with a discharge of 1.8 m^3/sec, carried the Sea of Okhotsk a daily load of over 65 etric tons of dissolved aluminum and about 35 ns of dissolved iron [11, 12].

The main factors affecting the behavior of ese elements in the process of leaching and edistribution are as follows:

1) geochemical properties of the elements themselves, chiefly the capacity of their compounds to precipitate out of solution at a specific hydrogen ion concentration (pH);

2) composition of the fumarole gases which determines the anion fraction of acid thermal waters and which depends on the stage of volcanic activity;

3) the presence and amount of ground water which dissolves the gases to become acids, as well as the amount of meteoric water which dilutes them, thus lowering their pH.

The behavior of iron and aluminum in thermal solutions is determined chiefly by the possibility of forming hydroxides of these metals from various compounds with different (but always specific) pH. Thus hydrate of ferric iron coagulates at pH = 2 to 3, while that of ferrous iron coagulates at pH = 5.5 [20]; hydrate of aluminum oxide is precipitated out of sulfate solutions at pH = 4.1, and at pH = 6.5 out of chloride solutions [4]. Inasmuch as Fe is present in the ferrous state in ground water and is rapidly oxidized when it reaches the surface, intensive precipitation of ferric iron takes place in thermal springs with pH greater than 3 (up to 5). Thus iron migrates freely either in ground water with pH less than 5.5 or in surface water with pH less than 2. Optimum conditions for aluminum are obtained when haloids predominate in the composition of fumarolic gases. A damping of volcanic activity, first signaled by the disappearance of haloids, prevents Al from passing into solution; it remains in the decomposition zone where it forms kaolin and alunite.

It should be noted, however, that a change in

[1]Peremeshcheniye i nakopleniye zheleza i alyumin- ya v vulkanicheskikh oblastyakh Tikhogo okeana.

the composition of gases as a result of damping the activity of a single volcano does not necessarily mean a change in the gas composition and a general change in volcanic activity for the entire province, because this activity is manifested in different ways in different areas of a volcanic zone. As was noted by G. M. Vlasov, "there are many volcanic chains where an early crater is no longer active, the next to it is a fumarole, the one next to that is in its full vigor, while the fourth one, represented usually by a slag cone, is in its formative stage; this phenomenon appears to be related to the plugging of volcanic vents by the eruption products, forcing the lavas and gases to find new outlets along the fault zone" ([8], page 169). Thus, the zones of an intensive acid dissociation of rocks in volcanic provinces shift gradually, involving ever new rocks in the decomposition process.

A third and very important factor affecting the redistribution of iron and aluminum is the amount of ground and meteoric water. In highland regions and in the craters of high, regular cones, where the water intake is very low, most volcanic gases are simply vented into the atmosphere, without forming any acids. Optimum conditions for the formation of more or less concentrated acids capable of holding the dissolved elements for a long time prevail under the normal hydrogeologic conditions of temperate latitudes, with an active participation of ground water. On the other hand, the abundance of precipitation, characteristic of tropical regions, may lead to an intensive dilution of thermal waters, a lower pH, and, as a consequence, to a cessation of the Fe and Al migration (as precipitates). Thus ground and meteoric waters, as a function of climatic conditions, turn out to be a most changeable factor which either permits or prevents the redistribution of iron and aluminum. This is the aspect in which we presently consider the great Pacific volcanic ring whose individual segments are active within most diversified climatic zones of the world.

THE KURILES AND JAPANESE ISLANDS

Out of 90 volcanoes of the Kuriles, 39 are active, about 10% of the world total (Figure 1). From a number of observations, the present-day volcanism of the Kuriles is "a weak echo of pre-glacial volcanism" [10], expressed mostly in intensive fumarolic activity almost throughout the entire Greater Kuriles ridge [9, 10]. As a result, extensive zones of altered rocks, carrying deposits of native volcanic sulfur, have been formed on both the extinct and active volcanoes [7, 18]. The fumarolic activity is accompanied by vigorous hydrothermal processes in a number of volcanoes such as Ebeko and Karpinskiy, on Paramushir Island; Krenitsin on Onekotan Island; Kuntominar on Shiashkotan Island; Ushishir on Ryponkich Island; Pallas on the Ketey Island; "Kudryavyy", Bogdan Khmel'nitskiy", "Machekha", and Berutarub on Iturup Island; Mendeleyev and Golovnin on Kunashir Island, etc. The calderas of Ebeko, Kronitsin, Pallas, "Bogdan Khmel'nitskiy", and Golovnin, volcanoes hold acid crater lakes. The discharge of very acid (pH = 1 to 2) thermal springs commonly is tens of liters per second. These springs give rise to numerous so-called "sulfur" streams flowing down the slopes of active volcanoes and to the Pacific and the Sea of Okhotsk. These include such acid thermal rivers as the Yur'yeva and Gorshkova on Paramushir; Mar'ya and Dar'ya on Urup; North and South Chirip, Gryaznaya, Sernaya, and Medvezh'ya on Iturup; Lesnaya and Ozernaya on Kunashir, etc. These rivers carry out to the sea various elements which passed into solution as a result of acid dissociation of rocks. In this process, the bulk of cations consists of aluminum and iron, whose content in acid springs is commonly grams per liter [12, 14].

Those thermal rivers, maintaining their low pH as far as their mouth, as the Yur'yeva which flows to he Sea of Okhotsk from a northern island and has a pH = 1.72, carry to the sea both the dissolved aluminum and dissolved ferric iron (65 and 35 tons per day, respectively, for the Yur'yeva). Iron and aluminum are separated in rivers and streams with a pH greater then 3: upon oxidation, as a stream emerges at the surface, iron is precipitated either as limonite at the bottom of the spring or else as a crust of "spongy" limonite which then changes to goethite. This phenomenon is most common on islands of the south group where the precipitated limonite forms commercial deposits. Thus a sizable deposit, the Limonite Cascade, has been formed along a chain of flowing lakes of the "Bogdan Khmel'nitskiy" caldera, as a result of the activity of a group of springs with pH of about 3 and a total discharge of about 60 liters per second. The limonite store grows at the rate of over a ton per day [12]. Limonite layers, many meters thick and formed by oxidized iron precipitated from thermal springs, have been observed on the Berutarube slopes (Iturup Island). In the Rudnichnaya and Gryaznaya thermal rivers (Pacific coast of the Iturup Island), iron hydroxide cements the alluvial deposits. Intensive accumulation of limonite has been observed at the mouth of Lesnaya River which gathers acid waters of Mendeleyev volcano, as well as in many other places, virtually everywhere that there are thermal springs with pH = 3 to 5. It should be emphasized that such limonites are extremely pure, with hardly any additions. Chemical analysis of a fresh limonite specimen from the Limonitovyy Protok, "Bogdan Khmel'nitskiy" caldera, is as follows (percentage of dry sample): SiO_2 — 0.36; Al_2O_3 — 0.55; Fe_2O_3 — 72.92; FeO — 4.06; CaO — 0.13; MgO — 0.14; Na_2O — 0.09; K_2O — 0.15; P_2O_5 — 0.93; SO_3 — 5.14; H_2O^+ — 13.29; CO_2 — 0.19 and C_{org} — 1.50; spectrographic analysis of a large number of limonite samples has revealed, in

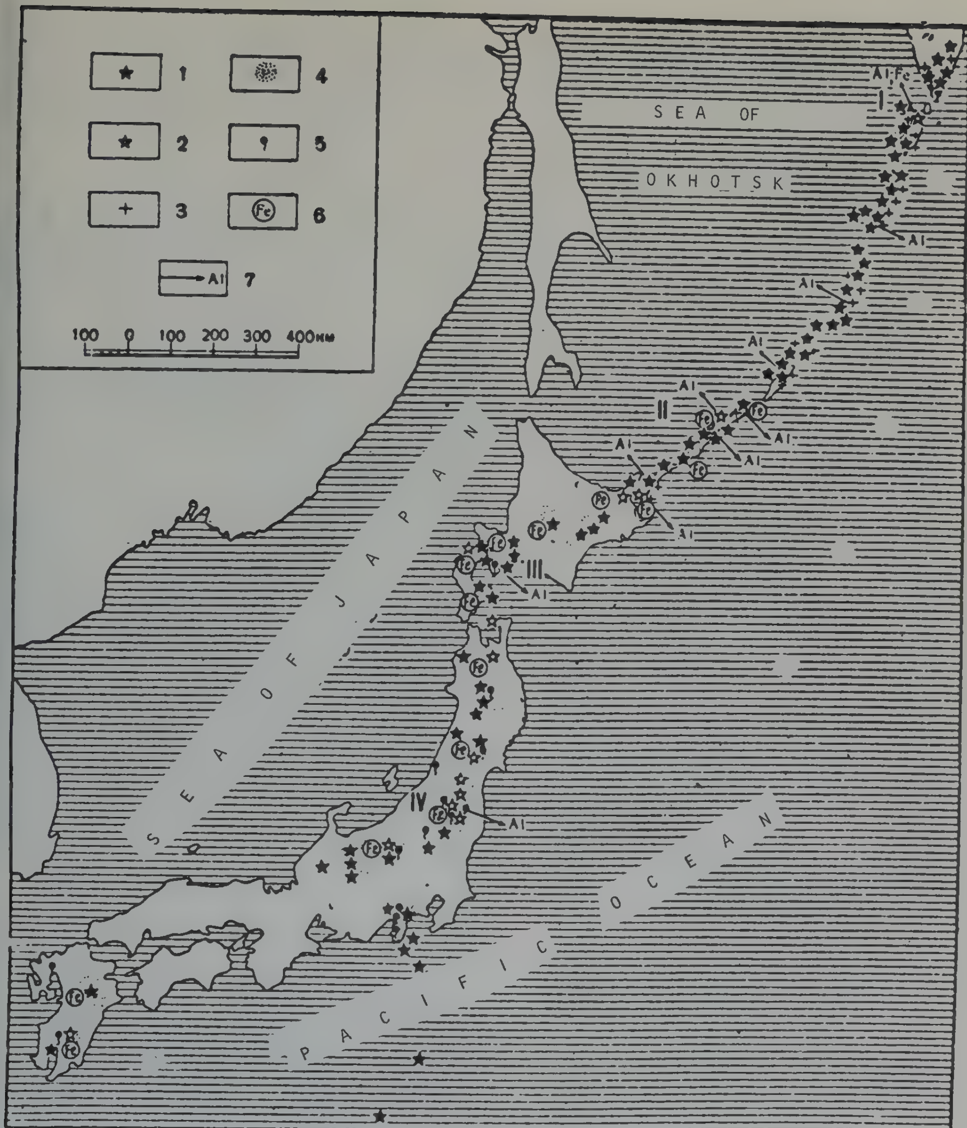


FIGURE 1. Transportation of iron and aluminum in the present volcanic provinces of the Kuriles and Japan.

1 - active volcanoes; 2 - active volcanoes with crater lakes; 3 - fumarole fields; 4 - zones of recent bleaching of rocks; 5 - acid springs; 6 - terrestrial accumulations of ferric iron; 7 - transportation of dissolved aluminum out to the sea; I - Yur'yeva River; II - Limonite Cascade deposit; III - Kutian deposit; IV - Humma deposit.

ddition, very small amounts of Mn, V, and i.

The same situation prevails on the Japanese slands where about 30 of more than 200 known olcanoes were active earlier and now display vigorous famarolic and hydrothermal activ-y [27]. These volcanoes are concentrated on ne island of Hokkaido, the north half of Honshu, nd in the southern part of Kyushu; related to nem are scores of acid thermal springs with pH less than 3.9, especially numerous in the middle part of Honshu [26]. In waters of the Mantsu group of thermal springs typical of Japan, located on slopes of the Kusattu volcano (Humma district), the aluminum content reaches 245 mgm/liter, with a high chlorine content [33]. Related to the volcanoes are many acid crater lakes such as Katanuma located on a volcano of the same name, with an area of 0.15 km^2, maximum depth of 22 m, and pH = 1.4, at a temperature of 24°C; also related are the

Bosikinum group of lakes on the northern slope of Banday volcano, consisting of 80 small lakes drained by an acid river with pH = 4. 5; the large caldera Lake Nikuzima which gathers up acid waters of Numuziri Volcano; the Dzao crater lake with pH = 2. 2; and over ten acid lakes in the craters of other volcanoes [29]. As a result of the action of acid thermal waters on extrusive rocks, the Japanese islands contain many bleached zones often carrying deposits of native sulfur [6, 30]. Associated with the same areas are the numerous deposits of sedimentary limonite of Japan [16, 27, 30].

These limonite deposits, usually called bog ores, are one of the most important resources of Japanese industry, and their geology is known in detail. T. Mitsuhi states ([16], page 364), "Although these deposits are formed by iron-bearing spring water, they are not always located near them but rather in depressions some distance away. Accordingly, the bog-ore deposits are found on mountain slopes, in valleys, on terraces, in alluvial plains, and especially in swamps. On the whole, their occurrence is related more closely to present topography than to subsurface structure. Host rocks of such deposits are represented by volcanics and pyroclastics of the andesite, liparite, agglomerate, tuffs, and volcanic fragmental types. Ore deposits form stratified to lenticular bodies, in a comparatively sharp contact with the enclosing rocks. Their outlines in plan are different in different localities. Some deposits are rounded to elliptical; others are elongated. Their thickness ranges from less than 1 m to more than 30 m. As a rule, they are thin at the periphery and thicker toward the center".

The most important mines working bog ores are located on Hokkaido (the Kutian deposit) and in northwestern Honshu (Humma), i. e., in areas of the most intensive volcanic activity. The Kutian ore body is associated with terrace deposits, chiefly of pyroclastic material. Numerous ore bodies, 2. 5 to 30 m thick, are buried under 5 to 25 m of drift. The Humma ore body is located at the foot of the active Kusattu volcano and is 2000 m long and 30 to 200 m wide in an ancient valley. "In the middle part of the valley, the thickness of the ore body is variable, being about 20 m in the upper course of the stream, 10 to 20 m in the middle course, and only a few meters thick in the lower course, where it thins out. A small basin-type depression has been observed at the headwaters, suggesting the source of mineral springs which have formed the bog ore" ([16], p. 366). The average iron content in the Humma bog ore is 49. 5% [27].

Obviously, bog ores of Japan are identical in genesis, to the Kuriles limonite accumulations. Inasmuch as large amounts of aluminum has been found in hermal waters of both the Kuriles and Japan, while no aluminum is being deposited in limonites of either region, it can be stated with certainty, despite the lack of direct evidence, that much aluminum is leached and carried out to the sea, in the Kutian-Humma area and probably in many other places in Japan, as is the case in the Kurile Islands.

The process of leaching of metals by acid thermal waters, as already pointed out, is determined by the presence of ground waters which dissolve volcanic gases and turn to a mixture of various acids. These waters originate fully from meteoric waters, which simultaneously dilute them to a considerable extent, thereby lowering their pH. Calculations have shown that meteoric waters of the Kuriles and Japan, amounting to 1000 or 2000 mm annually [3], are capable of raising the pH of river waters related to thermal springs to 2 to 5, at the most. In other words, the prevailing dilution is generally inadequate for a precipitation not only of aluminum, but of ferric iron as well. For that reason, in the northern part of the Kurile Ridge, where the atmospheric precipitation is at its minumum and where there are rivers with pH less than 2 (e. g., the Yur'yeva), both aluminum and iron are carried out into the marine basins. On other islands as well as in Japan, where pH of waters fed by thermal springs ranges on the whole from 3 to 5, the marine basins receive mostly aluminum. The bulk of iron, emerging as ferrous and oxidized at the surface to the ferric state, is concentrated on volcanic slopes and in topographic depressions, as a limonite crust or as iron bog ore.

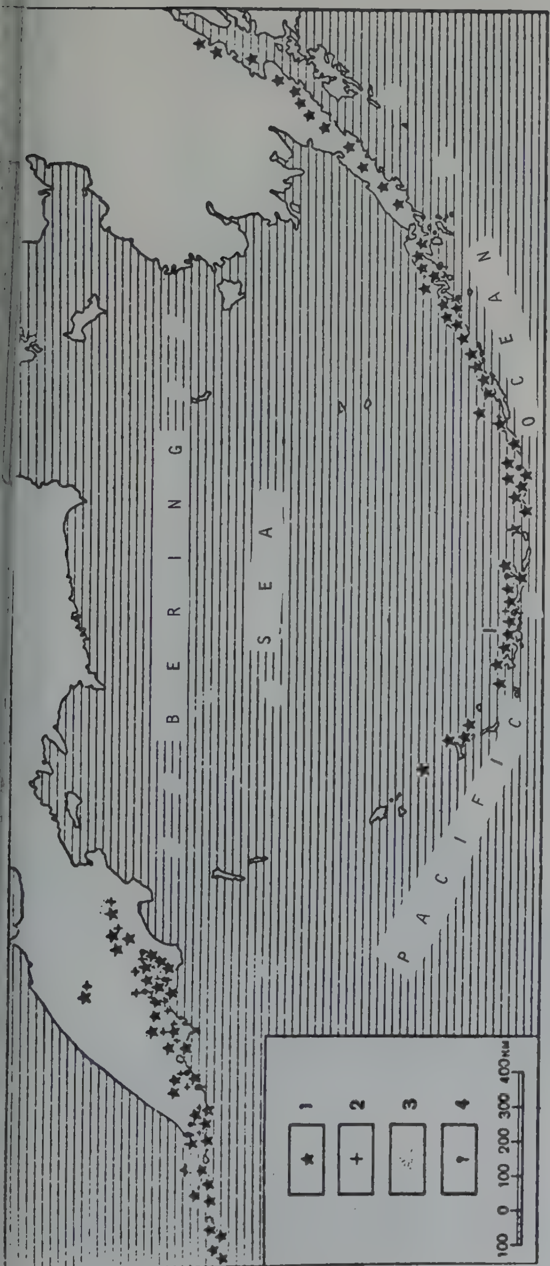
ALEUTIAN ISLANDS

In intensity of volcanic activity, the Aleutian island arc is a close second to the Kuriles (Figure 2). It includes (outside of Alaska) over 20 active volcanoes, with a record of numerous earlier major eruptions which led at times to a modification of the island outlines and to the emergence of new islands (such as the appearance of the Bogoslov island volcano in 1796). However, thermal springs are rare, here, and crater lakes are altogether missing [24]. An exception is the Bol'shoy Sitkin volcano (on the island of the same name) where there is a large zone of bleached and decomposed rocks, intensive fumarolic activity, and acid thermal springs with pH of about 2 and a high chlorine content [38].

This paucity of the Aleutian arc in crater lakes and acid thermal springs becomes understandable if we consider the climate of the Aleutian Islands. Winter lasts here most of the year with precipitation, which amounts to about 1000 mm, accumulating as snow. "Snow begins to fall in September and even in August and persists into May. In the mountains, it snows in June. Thus, snowless days occur only in July" ([13], p. 225). In the short periods of a thaw, water rapidly runs off the frozen ground and to

FIGURE 2. Hydrothermal activity in present volcanic provinces of Kamchatka, the Aleutians, and Alaska

1 - active volcanoes; 2 - fumarole fields; 3 - zones of recent bleaching of rocks; 4 - acid springs; I - Bol'shoy Sitkin Island.



the sea, at best only moistening the upper layer of soil. No ground water is formed. For this reason, he process of rock decomposition, and the redistribution of iron and aluminum with it, are considerably depressed despite the intensive fumarolic activity of the Aleutians. They are present only in isolated and favorable localities. The leaching and transportation to the sea of iron and aluminum by waters of this province are virtually non-existent.

INDONESIAN ARCHIPELAGO

About half of all active volcanoes of the world are concentrated on a few islands in the Indonesian Archipelago. According to R. Van Bemmelen [2] and N. Van Padang [34, 35], over 500 volcanoes are known there, among them, 177 active ones (Figure 3). There are 88 fumarole volcanoes and fields located along the Indian Ocean coast of the islands of Sumatra and Java (21 and 36 volcanoes, respectively), on the Lesser Sunda Islands (ten volcanoes), at the northeast tip of Celebes (seven), in New Guinea (three), and the Philippines (eleven).

The abundance of hot springs and crater lakes, two or more on some fumarole volcanoes, is typical of the Indonesian Archipelago. The springs are mostly acid with a high content (as much as several grams per liter) of dissolved iron and aluminum, while the crater lakes are immense reservoirs of acid water. It is enough to mention the Idjen crater lake at the eastern tip of Java; according to R. Van Bemmelen [2], it is the largest reservoir in the world of very acid waters, holding about 40 million cubic meters of water with pH = 0. 02, and with an Al_2O_3 and Fe_2O_3 content at 8. 7 and 2. 3 gm/liter, respectively.

This abundance of acid thermal waters in volcanic provinces of the Indonesian Archipelago is due to the very considerable amount of atmospheric precipitation. In most of Indonesia, the annual precipitation is 2000 to 3000 mm, with over 4000 mm on windward slopes [15]. The annual precipitation in central and western Java is over 7000 mm, with isolated areas of the Philippines registering up to 9000 mm. Precipitation of over 1000 mm in 24 hours [2] has been recorded on Luzon; this is about as much as the annual precipitation on some of the Kurile Islands.

The broad development of fumarole activity together with the abundance of moisture unavoidably leads to an acid treatment of volcanic rocks. The metals are leached out and carried away, as witness the numerous fumarole fields of rocks devoid of iron, aluminum, and other metals. Two islands alone, Java and Sumatra, have over 30 such fields.

What happens to the immense amounts of iron

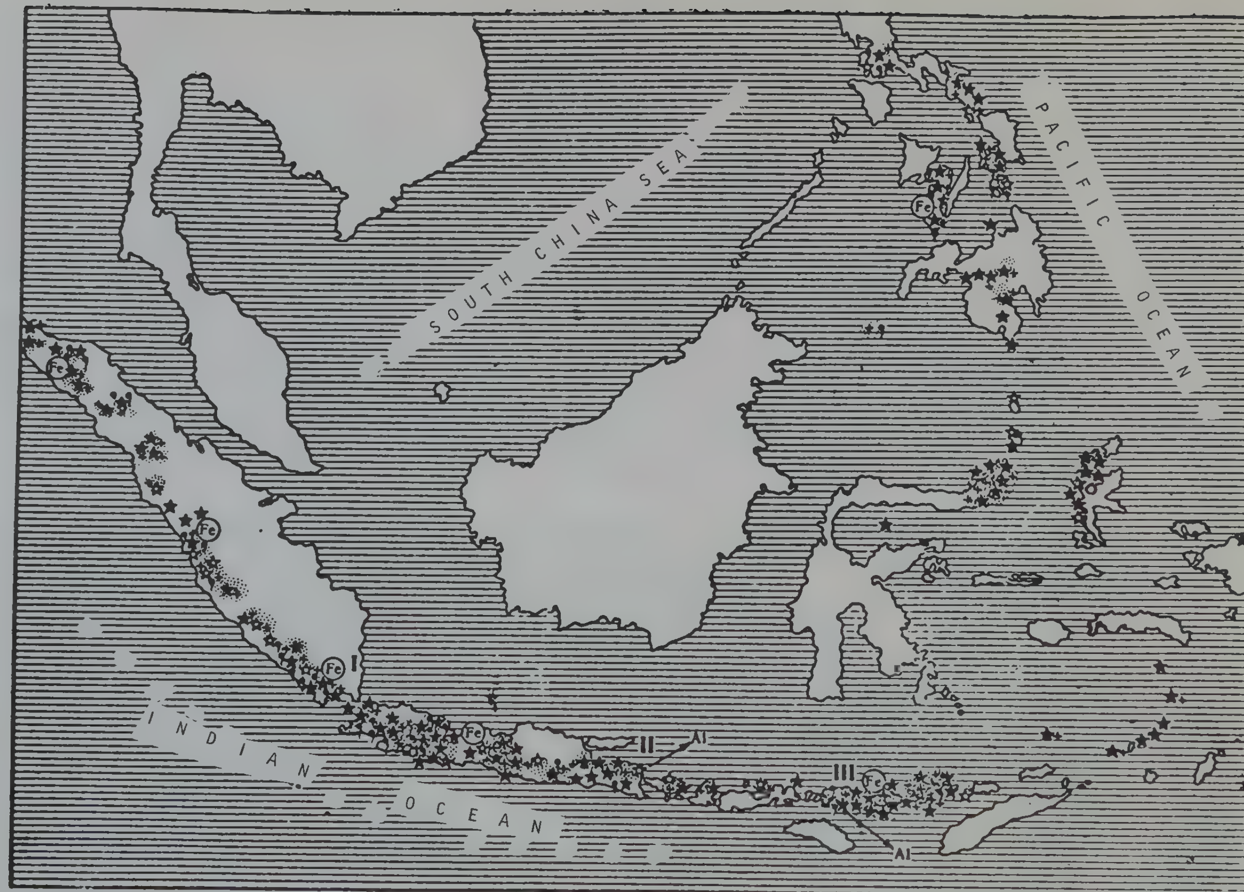


FIGURE 3. Transportation of iron and aluminum in volcanic provinces of the Indonesian Archipelago

Symbols, see Figure 1. I - Vey-Vey limonite field; II - acid crater lake Idjen; III - the Flores Island iron-ore deposits.

and aluminum carried away by acid waters? What is the behavior of these elements under the very humid Indonesian conditions?

The Indonesian Archipelago is known to possess many major and minor iron ore deposits, concentrated mostly in the areas of active volcanism. A sizable portion of these deposits consist of stratified bodies almost fully composed of iron hydroxides and resting on the most diversified rocks, extrusives, shale, sandstone, and even limestone [32]. Unfortunately, the students of Indonesia, unlike their Japanese collegues, have made no attempt to relate these ore bodies to hydrothermal volcanic activity; they voiced instead other ideas about their origin. Because of that, the geologic material, briefly summarized in works of E. Mohr [31] and R. Van Bemmelen [21], with a definite slant and often from old and virtually no longer accessible data (reports of industrial organizations, short communications, etc.), is naturally incomplete and very difficult to use. However, even these meager descriptions permit a glimpse of the similarity of these deposits to the corresponding formations in the Kuriles and Japan.

For instance, the Vey-Vey ore field in the Lampong Province (East Sumatra), is represented by four low hills made up almost fully of limonite. A drift driven through the highest 13-meter hill, shows that the ore is 14 m thick, i.e., the hills are standing on a comparatively level platform in extrusive rocks. The ore is exceptionally pure, with Fe_2O_3 + FeO amounting to 95%. Titanium is totally absent in the upper zone, with some traces of it in the lower zone where some enrichment in SiO_2 has been observed (undoubtedly, it is of a terrigenous origin). In addition, the content of Al_2O_3, MnO, and SnO is somewhat higher (within 1%) in lower zones (Table 1). The ore reserves of these deposits are estimated at 835,000 metric tons [21].

Judging from their description, liminite hills of the Vey-Vey field are startingly similar to those of the Limonite Cascade ore deposits on Iturup Island (Kurile Ridge) where 12-meter high limonite hills, formed as a result of precipitation of Fe_2O_3 from thermal waters, are standing amidst the extrusives of a level plain [12]. Both localities are identical in composition (Table 1), occurrence, and extent of ore bodies.

In other Sumatra localities, sedimentary limonite beds are present in the Sukadana Mountains where the so-called "bog ores" are represented by almost pure limonite (72.74% Fe_2O_3), 1 to 1.5 m thick, located at the edge of basalt flows; isolated areas of this ore are present in the Radjabaz mountain (11 km from the summit); boulders of "porous" limonite, formed most probably in the breaking up of sheets and hills similar to those of Sukadana and Vey-Vey, have been observed on Sumatra: at Kvala Boye and Tzhot Pluye, Via, Tapa Tian, and elsewhere. In Java, sedimentary limonite rests on volcanic breccia and conglomerate of South Priangan and on slopes of the Gunung Petiardzhem volcano; on Flores Island, on Volo Bezi, Volo Bopo, Volo Akor mountains, and on slopes along streams on Vay Bero and Vay Mere, etc. [31]. Everywhere that it was possible to ascertain, sedimentary limonites are located in the vicinity of fumarole volcanoes (Figure 3).

To be sure, these ore deposits by no means reflect the entire scope of this process; however, they are sufficiently convincing that the accumulation of limonites near volcanoes, in the Indian Archipelago, is similar to that of the Kuriles and Japan.

The situation appears to be different with relation to aluminum. Red soils of western Indonesia are known to carry considerably amounts of free alumina which is the predominant component in some areas. This phenomenon has been explained, as a rule, by lateritization, i.e., by leaching of silica and an accumulation of residual alumina. However, the absence of free Al_2O_3 in drained areas, along with its preponderance in lowlands, i.e., in marshes, rice fields, and river vallyes, suggests that we deal here with added free alumina rather than with the residual. The accumulation of added Al_2O_3 is the deposits of dry lakes on a karst limestone plateau near Jokyakarta is especially characteristic. As described by E. Mohr [31], they are red earths, very similar to the "terra rossa" type formations, and containing much aluminum hydroxide.

It is of interest that the students of this lateritic process are very cautious in hypothesizing a lateritic origin for these earths from western Indonesia. T. Dames [25], who studied the brown and red soils which cover most of Java and are developed chiefly on Pliocene and Quaternary volcanic material, denies their lateritic origin; he believes that true laterites have not been found yet on Java. J. Prescott and R. Pendleton, in summarizing their study of the structure of Indonesian soils, conclude as follows: "There is no doubt that soils red in color and rich in oxides of iron and aluminum are not necessarily lateritic or even close to laterites" ([36], p. 39).

We believe that it is here that we should look for aluminum which lost its migratory facility as the result of an intensive (more than tenfold compared with the Kuriles and Japanese islands) dilution of thermal waters by meteoric waters. The accompanying rise in pH in flowing water often forces the aluminum hydroxide to coagulate and precipitate, long before these waters reach the sea. Consequently, unlike the situation in the Kuriles and Japan, alumina is deposited along with silica in the "bog"

TABLE 1

Composition of limonite from East Sumatra and the Kuriles

Area	Sampling locality		SiO_2	Al_2O_3	Fe_2O_3	FeO	TiO_2	MnO	CuO	SnO_2
East Sumatra [21]	Drift in a 14-m hill in the Vey-Vey field, upper zone		1.95	0.23	93.20	2.67	None	0.50	0.03	0.12
	Same, middle zone		9.60	0.53	84.85	1.03	Trace	1.20	0.08	0.78
	Same, lower zone		21.80	0.86	67.48	1.20	"	1.00	0.05	0.96
The Kuriles [12]	Iturup Island	Tikhoye Lake, sediment	1.61	1.29	56.73	10.75	0.06	—	—	—
		Limonitovaya Protoka	0.38	0.55	72.92	4.06	Trace	—	—	—
	Kunashir Island	Kislyy Creek	8.53	3.02	61.56	2.82	0.36	—	—	—
		Lesnaya River, sediment	1.87	0.62	70.62	1.49	0.33	—	—	—

deposits of Java and Sumatra. This is corroborated by Hartman who established, as early as 1933, that a brown-red to yellow sediment with a 67.8% Fe_2O_3 and Al_2O_3 mixture has been found from brown-yellow to brown-red waters of "secondary" (apparently related directly to surface waters. K. Z) thermal springs with pH = 8.6, which appeared after the Merapi volcanic eruption [2].

Shallow water, littoral marsh pure iron-ore deposits of the Japanese type are present only on the north coast of Flores Island, southeastern Indonesia, in a region of comparatively low annual precipitation (1000 to 2000 mm). This region embraces the southeastern part of Java, Sumbawa, Flores, and extends farther southeast, taking in the Sough Pacific and Coral Sea islands. Here, free transportation of aluminum out of the sea undoubtedly proceeded in full force, the same for similar conditions of the Kuriles and Japan. Only a very small portion of undissolved aluminum does not reach the sea and is deposited instead in the above-mentioned acid Lake Idzhen.

Thus, we observe in a segment of the Pacific area, from the northern Kuriles to the Coaral Sea islands, a great process wherein extrusive rocks are reworked by acid thermal waters, with comparatively pure iron and aluminum isolated and redistributed. In the equatorial zone, with its overabundance of precipitation, further migration of iron is ruled out, while that of aluminum is hampered. Adjoining this zone in the north and in the south are provinces of lower precipitation, where migration of iron is hampered but that of aluminum is fully possible. In isolated areas of these provinces, conditions may exist for a joint migration of both iron and aluminum. Finally, there are provinces of the Aleutian-arc type, where the process of reworking volcanic rocks and of redistribution of iron and aluminum is suppressed to a considerable extent because of the lack of ground water (Figure 4).

What then is the fate of the large amount of aluminum which has been carried out to the sea, north and south of the equatorial zone?

Upon arriving at the sea, thermal waters are neutralized and their aluminum and iron go into suspension as hydroxides. This reaction takes place in the uppermost marine film and requires for its completion considerable volumes (a thousandfold and more) of sea water; this accounts for the long turbidity trains of many kilometers, at the mouths of thermal rivers, where $Al_2O_3 + Fe_2O_3$ are formed far away from shore [12].

In the northern part of this province, near the Kuriles and Japanese shores, conditions favorable for an accumulation of the aluminum and iron hydroxide suspension are missing. Here, the suspension is mixed with a large amount of terrigenous material; under the hydrodynamic conditions of the Pacific and the Sea of Okhotsk it is dispersed, for all practical purposes.

The situation is different in the South Pacific where coral islands, standing in clear water with atolls protected from wave action, happen to be just where most aluminum is brought from volcanic areas.

Table 1 (cont'd)

CaO	MgO	Na_2O	K_2O	P_2O_5	As_2O_3	S	SO_3	CO_2	C	H_2O+	Total	H_2O-
0.20	0.20	—	—	0.02	0.01	—	None	0.40	—	0.50	100.03	—
0.10	0.10	—	—	0.44	0.01	—	Trace	0.20	—	1.70	100.62	—
0.20	0.20	—	—	0.57	0.01	—	"	None	—	5.95	100.28	—
0.27	0.23	1.48	0.23	1.33	—		7.78	0.85	0.06	16.89	99.56	71.51
0.13	0.14	0.09	0.15	0.93	—	»	5.14	0.19	1.50	13.29	99.45	24.82
0.19	0.05	0.11	0.15	0.25	—	1.15	8.12	0.14	0.70	14.13	101.28	52.97
0.11	0.03	0.08	0.13	0.32	—	0.30	8.20	0.43	1.80	13.87	100.20	64.33

A survey of the literature shows that soils of southern coral islands ("Red Earth" of American geologists) carries much Al_2O_3, with very low SiO_2/Al_2O_3 ratios [23]. For example, in the western Samoan Islands, SiO_2/Al_2O_3 = 0.12 to 0.54; it is 0.33 on the Solomons, and less than 0.04 on Niue Island [28]. Everywhere, these soils rest on coralline limestones; students often emphasize the complete lack of connection between these soils and the insoluble remains of underlying carbonate rocks. The prevailing opinion is that these soils have been formed in the decomposition of volcanic rocks by surface processes.

However, some data extant suggest that caution should be exercised in the approach to this hypothesis, as well. A closer look at the description of Niue Island is helpful [22, 37].

The island of Niue is located northeast of New Zealands, near the Tonga islands (on the side of the Tonga trough opposite to them). It is a solitary flat coral island, measuring 25 by 20 km, surrounded by depths of about 5000 m, which precludes any connection between it and other mountain structures of the recent past. It is made up fully of coral reefs of different generations, now represented by very pure limestone, without any evidence of extrusive rocks. The island has stood repeatedly above and below sea level, as indicated by the mighty coral reefs, on one hand, and by a series of marine terraces of different elevations, on the other.

The surface of one of these terraces (75 m above sea level) is covered by some 30 m of soil, very uniform in composition, as shown by six analyses. One of the analyses is as follows (in %): SiO_2 – 0.32; Al_2O_3 – 38.58; Fe_2O_3 – 28.54; TiO_2 – 1.50; P_2O_5 – 2.02; Cr_2O_3 – 0.22; CaO – 1.67; MgO – 0.55; Na_2O – 0.04; K_2O – 0.01; MnO – 0.05; losses in heating, 26.64. It appears that the bulk of this "soil" is represented by hydroxides of iron and aluminum.

Slime cake was gathered from another terrace (25 m above sea level); its analysis (in %) is as follows: SiO_2 – 0.6; Al_2O_3 – 5.5; Fe_2O_3 – 3.0; TiO_2 – 0.1; P_2O_5 – 4.0; CaO – 27.6; MgO – 1.7%; losses in heating, 55.5. Undoubtedly, here, too, we deal with a ferruginous-aluminous body, impoverished by an addition of clastic calcite.

Meteoric waters are concentrated in reef limestone of the central part of the island where they do not carry any silica. Silica is missing also in the reef limestone itself which is only slightly dolomitic.

The theory which explains the formation of the Niue Island soils as an aeolian accumulation of volcanic ash and its subsequent and complete decomposition [22, 28, 37] has many obscure points. It is impossible to explain satisfactorily why an aeolian accumulation takes place on some marine terraces, which brings about the alleged total decomposition of ash on Niue Island, while ash deposits on the neighboring island volcanoes (such as those of the Cook Islands) are quite intact under the same conditions. Finally, what happened to the products of this decomposition, particularly SiO_2? On the

other hand, the fairly detailed description of the island contains no evidence which militates against a marine origin for these deposits.

Obviously, what we see here is a result of the processes of redistribution of iron and aluminum described above. Soils of Niue Island and the similar "red earths" of South Pacific coral islands have nothing to do with the dissolution of limestone, nor with the aeolian transportation and decomposition of volcanic ash. These are rather accumulations of $Al_2O_3 + Fe_2O_3$, formed in the sea as a result of precipitation of iron and aluminum hydroxide brought in, in solution, by thermal waters.

Accumulations of marine bauxite rocks, similar to the Niue terrace "soils", were observed by C. Trechman [40] on Pleistocene coral reefs off the northern coast of Jamaica where climatic conditions are similar to those of Japan [3], and not far from near-shore active volcanoes of the Antilles arc and the Isthmus of Panama. The "coralline rock" (according to Bushinskiy, [5], p. 220) has been altered in spots to a drab-brown mass, down to 0.3 to 0.6 m, in a fringe about 30 m wide. Dendritic

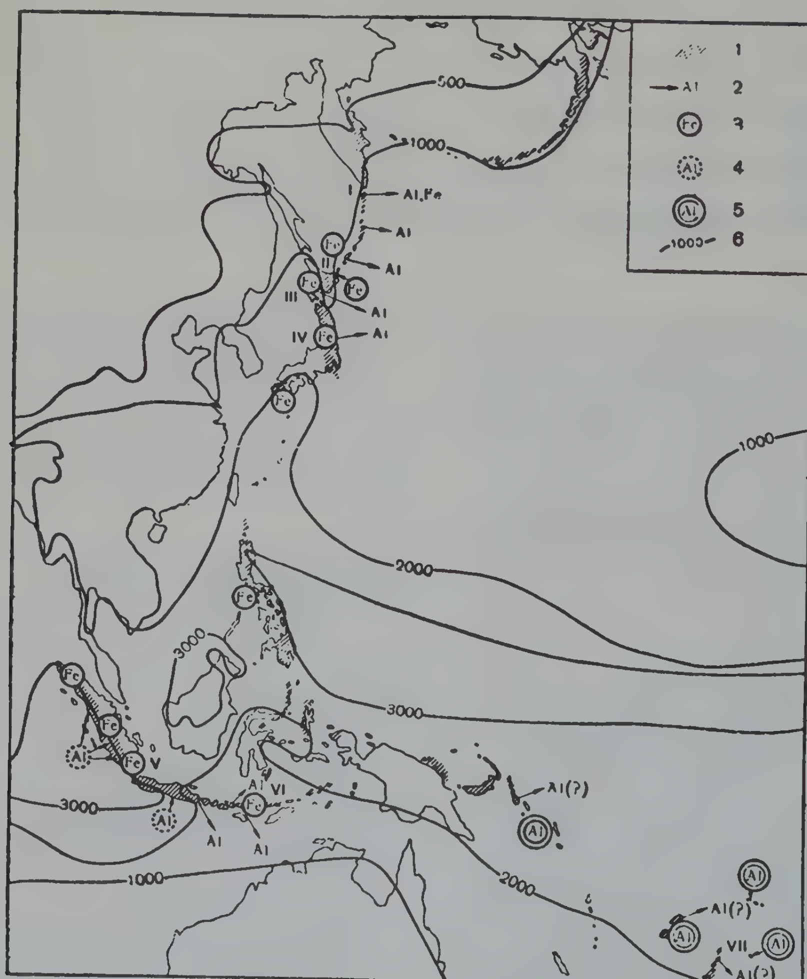


FIGURE 4. Transportation of iron and aluminum in provinces of present volcanism in the western Pacific

1 - present volcanic provinces; 2 - transportation of aluminum out to sea; 3 - terrestrial accumulation of ferric iron; 4 - aluminum accumulation in soils; 5 - aluminum accumulation on coral islands; 6 - isohyets (in mm, after L.S. Berg); I - Yur'yeva River; II - Limonite Cascade deposit; III - Kutian deposit; IV - Humma deposits; V - Vey-Vey deposit; VI - Flores Island; VII - Niue Island.

...d massive corals are conspicuous in this ...ass. This altered fringe is developed along the ...ore, in the surf zone, and locally in depres-...ons where sea water evaporates, leaving behind ...thin salt crust. There is no trace of this ...rown rock, either beyond the surf zone or in ...ower tertiary beds which support the coral ...eef. Its chemical composition is as follows (in ...): SiO_2 – 9.60; TiO_2 – 0.75; Al_2O_3 – 29.67; ...$_2O_3$ – 6.53; $MgCO_3$ – 8.30; $CaCO_3$ – 21.33; ...Cl – 0.53; losses in heating, 14.64%.

C. Trechman notes a slight development of ...ese bauxite rocks even on white limestone ...rming the coast line. True bauxites are not ...resent near the coast; they are known from 80 ...m west of Port Antonio, Jamaica. The origin of ...arine bauxite remained a mystery to C. Trech-...an. He believes that alumina and other mate-...al could have come from horizons underlying ...e submarine slope and fixed on rocks because ...f the development on them of green algae.

There is no doubt that we have here another ...xample of marine transportation of an Al_2O_3 ... Fe_2O_3 suspension, precipitated as a result ...f the mixing of thermal and marine waters, and ...s subsequent accumulation on coral reefs of ...he surf zone.

A comparison of the analyses of suspensions ...rom the estuarine zone of Yur'yeva River and ...he littoral zone of Paramushir Island [12], as ...ell as of marine bauxites on reef limestone ...rom the surf zone of the northern coast of ...amaica [40] with the Niue Island marine ter-...ace "soils" [37], presented in Table 2, shows ...hat the basic material, a suspension of Al_2O_3 + Fe_2O_3, is the same, everywhere. In the estuarine zone of Yur'yeva River, this mixture is diluted by terrigenous SiO_2 and by marine salts; in the littoral zone of Paramushir Island, it is diluted by organic $CaCO_3$. At Paramushir Island, Al_2O_3 + Fe_2O_3 occurs in its purest form, flushed of carbonates and marine salts.

One cán be sure that a special study of coral reefs of the Caribbean and the Coral Seas, carried out in the light of this process, will uncover new examples of Al_2O_3 + Fe_2O_3 suspension, redistributed and deposited by the sea.

What are the possible limits of transporting Al_2O_3 + Fe_2O_3 in sea water? It appears that distances of humdreds of kilometers do not constitute an obstacle to the migration of iron and aluminum in the upper sea water film. This is corroborated by a rough calculation which shows that the emptying into the sea of a single crater lake, such as Lake Idjen on the western tip of Java (40 million m^3), will involve a volume of sea water a million times larger than that of the lake (in raising the pH from 0.02 to 6.5), so that a ten-meter layer of it will cover an area of 4 million km^2, which equals the entire Coral Sea aquatorium. The involvement of an immense body of water naturally leads to a considerable dispersion of the suspension. This probably explains the fact that the suspension accumulates only in the area of coral reefs, i.e., where water is exceptionally clear.

These phenomena have undoubtedly recurred several times in the geologic past, as witness the bauxite deposits on the surface of Eocene and

TABLE 2

Composition of the Al_2O_3 + Fe_2O_3 suspension along the Sea of Okhotsk, Jamaica, and Niue Island Coasts

Nature of sediment	SiO_2	Al_2O_3	Fe_2O_3 + FeO	TiO_2	MnO	$CaCO_3$	$MgCO_3$	NaCl	$CaSO_4$ + $MgSO_4$	P_2O_5	C	H_2O+	Total
Splashes of suspension on the littoral-zone rocks on Paramushir Island [12]	20.94	20.73	14.79	0.69	Trace	0.30	None	9.75	4.25	1.80	5.31	15.87	94.43
Bauxite on Pleistocene reef limestones in the surf zone on the northern coast of Jamaica [40]	9.60	29.67	6.53	0.75	—	21.33	8,30	0.53	—	—	—	14.64	91.35
Soils of Niue Island [37]	0.32	38.58	28.54	1.50	0.05	2,98	1,15	—	—	—	—	24.73	97.85

Miocene limestones in littoral areas of Jamaica and Haiti, Mesozoic and Paleozoic bauxites of central and southern Europe and Turkey, in the Carboniferous of Central Asia, and in the Devonian of the Urals and Salair, all very close to the Jamaica bauxites in condition of occurrence. It is this group of chemogenic bauxite deposits that A. D. Arkhangel'skiy [1] has designated as marine bauxites, at the same time suggesting the necessity of revising our concepts of the origin of Mediterrannean bauxites.

In conclusion, it should be stated that what has been said above by no means denies the existence of soil-forming processes in tropical and subtropical regions, in the course of which oxides of iron and aluminum are liberated and accumulated. Such slow processes operate over broad expanses of large continents, in Brazil, equatorial Africa, northern India, and may lead to the formation of commercial deposits, under favorable conditions. There is no doubt but that they are operative on tropical volcanic islands as well. Such appears to be the origin of residual iron ores enriched in chromium and nickel and resting on flat serpentine massifs of Borneo, Mindanao, and of the small islands north of Mindanao [19, 21, 39]. It is also very probable, however, that most so-called "redeposited laterites", characterized by the diversity of underlying rocks, their very low silica content, the purity of composition, and their very fine grain, have originated from a redistribution of iron and aluminum by thermal acid waters, and have been formed in a manner similar to that of the Kuriles and Japanese bog iron ores. This is quite understandable because, in provinces of active volcanism of the island arcs, the slow process of lateritic soil making is subordinate to the incomparably faster process of decomposition of large bodies of extrusive rocks by acid thermal waters, accompanied by a redistribution of the decomposition products (chiefly iron and aluminum), and their subsequent accumulation.

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MAIN GENETIC FEATURES OF SOME INFILTRATION-TYPE HYDROTHERMAL URANIUM DEPOSITS [1]

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The geochemical history of uranium is determined to a considerable extent by its chemical properties [1]. One of the outstanding features of this element is that many of its hexavalent compounds are readily soluble in water; on the other hand, salts of tetravalent uranium, in slightly acid to slightly alkaline water solutions (pH = 6 to 9), typical of the lithosphere (at least down to 5 km), are marked by their low solubility and their tendency to hydrolyze. Hydrates of tetravalent uranium so formed are barely soluble.

As a result of that, as noted long ago by V. I. Vernadskiy and other students [1, 8], uranium is very mobile geochemically, under oxidation conditions; conversely, it usually does not migrate in aqueous solutions, in those segments of the lithosphere where strongly reducing condictions prevail.

A study of the behavior of uranium in ground water (down to 4 km below the feeder sources of aquifers) has shown that this general statement is fully applicable to their geochemistry, as well [4].

It has been demonstrated [4, 7, 8] that one of the main factors determining the behavior of uranium in ground water is the oxidation-reduction potentials of the "solid material of the lithosphere $\rightleftarrows$ aqueous solution" natural system. At the present time, we can judge it chiefly from the Eh of ground water separated from the solid phase of this system. However, this is adequate for evaluating the oxidation-reduction potentials of this system, as a whole. In addition, sensitive indicators are provided by the amount and composition of gasses dissolved in ground water and of their microorganisms.

In the gree oxygen zone of the upper part of the crust (down to 0. 5 to 1. 0 km below the water table) [3], in places where pitchblende, pitchblende-nivenite, and nivenite ores are developed, ground waters, in breaking up these deposits, acquire $n\cdot 10^{-2}$ gr[liter of uranium. A fairly large amount of uranium is also picked up in the circulation of oxygenated waters through rocks ($n\cdot 10^{-6}$ to 10^{-4} g/liter). On the other hand, uranium does not migrate in hydrogen sulfide waters characteristics of greater depth and of shallow, disintegrating petroleum sturctures; here, both in the ore areas and away from them, the solutions carry only $n\cdot 10^{-7}$ to $n\cdot 10^{-8}$ gm/liter of uranium, i. e., considerably less than in many waters of the oxygen zone and even less than in sea water.

Relationship between the behavior of uranium in ground waters and the oxidation-reduction conditions becomes clear when data on the uranium content in oxygenated and hydrogen sulfide waters circulating in the ore areas of many regions are correlated with their Eh values (Figure 1). (In determining the Eh of free oxygen and the composition of dissolved gases, the samples were taken in such a way as to prevent water-air contact: the water was changed several times by circulation in a closed system; Eh was measured in a closed vessel). The graph shows clearly that the disappearance of oxygen in waters circulating through rocks (ores) with disintegrating organic matter is accompanied by a sharp drop in the oxidation-reduction potential as well as the uranium content [4].

The vigorous solution of uranium oxide ores gives place to precipitation of uranium from ground water, chiefly in the form of oxides. This is graphically expressed in the high limb of an oil-bearing artesian basin in one of the areas (Figure 2). Here, uranium-bearing vanadates originated from the oxidation of pitchblende-nivenite ores in the seepage zone of the ore-bearing beds, with a considerable portion of uranium carried by downward-flowing waters (containing $n\cdot 10^{-5}$ to $n\cdot 10^{-4}$ gm/liter uranium); in the free oxygen zone, down to 150 m below the water table, fractured and porous ore-bearing rocks are bleached (oxidation of organic matter) and limonitized (oxidation of pyrite). In these areas, the pitchblende-nivenite is poor in uranium, locally very much so.

[1] Osnovnyye cherty gidrogeokhimicheskikh usloviy formirovaniya nekotorykh infil'tratsionnykh mestorozhdeniy urana.

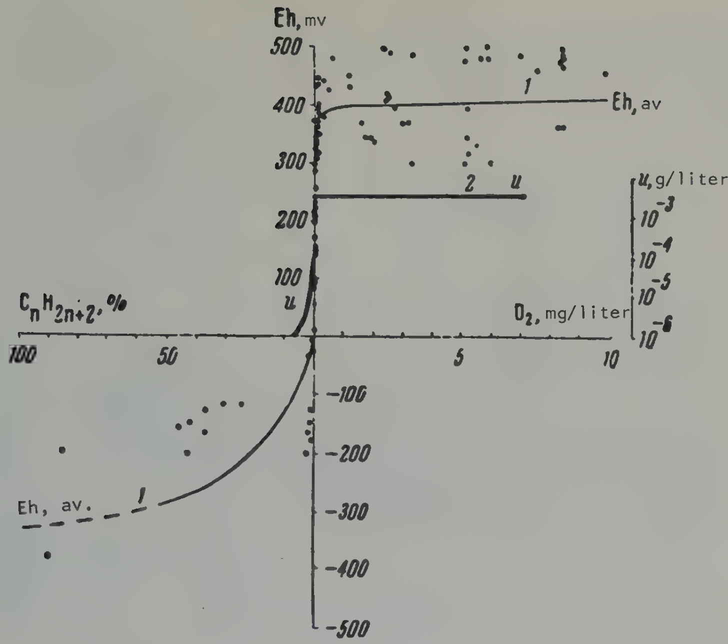


FIGURE 1. Uranium content in ground waters circulating in the ore area, below the water table, as a function of their Eh and dissolved gases.

1 - approximate curve of average Eh values for these waters; 2 - curve of not uncommonly high uranium content in waters contracting pitchblende-nivenite or nivenite ores.

The highly soluble uranium ($n \cdot 10^{-4}$ to $5 \cdot 10^{-2}$ m/liter) precipitates partly as uranium-bearing anadates; in contrast to the seepage zone, the atter are developed here at the site of an earlier nineralization, without any spreading. An even maller portion of uranium is fixed in this secndary mineralization than in the upper zone; he oxidation often proceeds without the formaion of its secondary minerals.

Going still deeper, these ore-bearing waters cquire definitely reducing properties, because of the abundance of petroleum organic matter Eh from -50 to -300 mv); they are also enriched n such strong reducing agents as biochemical ydrogen sulfide, hydrocarbon gases, and solule organic matter. At the same time, practically all of the uranium is precipitated out of the re-bearing waters, chiefly as uraninite and ivenite; according to I. G. Chentsov (1955), hese are united with solid bitumen, the oxidaion product of petroleum organic matter with high C/H ratio (up to 16). The abundance of iogenic carbon dioxide in this zone (as a result f the activity of desulfurizing, denitrifying, and ther bacteria) often brings about an intensive olution of carbonates (solution vugs and caverns, suture-stylolitic contacts, etc.). Silica s deposited here, in many places, bringing bout a silicification of rocks (I. G. Chentsov, 1955; G. A. Komarova, 1956), locally a very intensive one. Characteristically, in some areas the pitchblende-nivenite ores are formed in this zone of carbon dioxide — hydrogen sulfide — methane waters, in the redeposition of uranium captured by ore-bearing waters from decomposing ores of the oxygen zone. In other areas, young (Quaternary) ores have been formed by the concentration of uranium from freely circulating, abundant formation waters which leach it, in the oxygen zone, out of rocks ($n \cdot 10^{-5}$ to $2 \cdot 10^{-4}$ gm/liter) with a very high uranium content (Clark index) of $n \cdot 10^{-3}\%$.

One of the simplest manifestations of the mineralizationprocess as an effect of ground water action is the redeposition of uranium leached out of a uranium mineralization in the course of oxidation, with the upper boundary of the "cementation zone" now coinciding with the water table, then dipping under it. We now turn to some examples of this phenomenon.

Redeposition of uranium from formation waters as an effect of the presence of petroleum organic matter has been observed in deposits associated with bituminour limestone beds. One of them, located low on an aniclinal limb, and petroliferous in the recent past (at the close of the Neogene to the beginning of the Quaternary

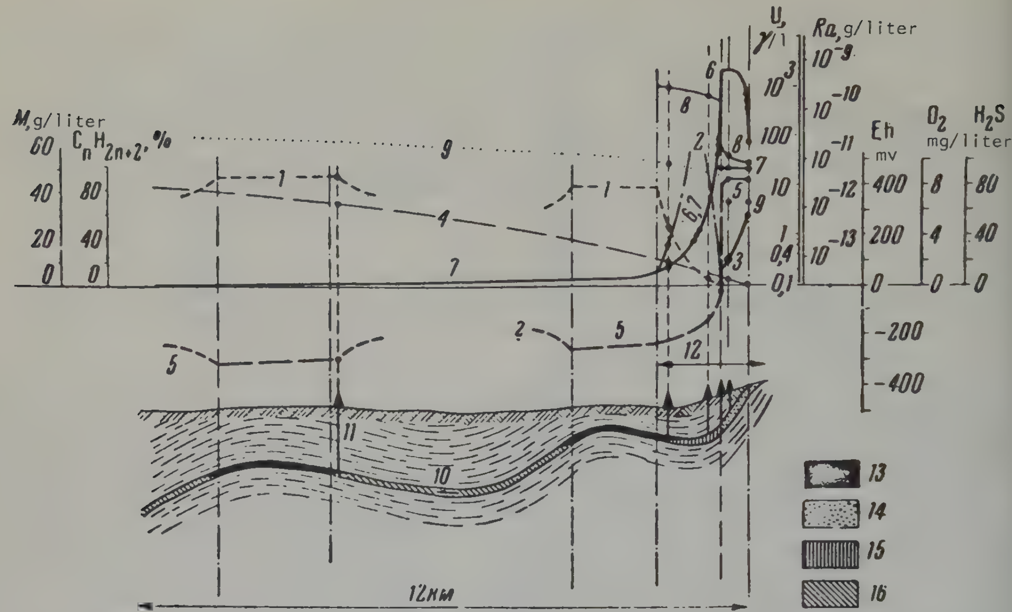


FIGURE 2. Hydrogeochemical cross-section of an oil and water-bearing bed

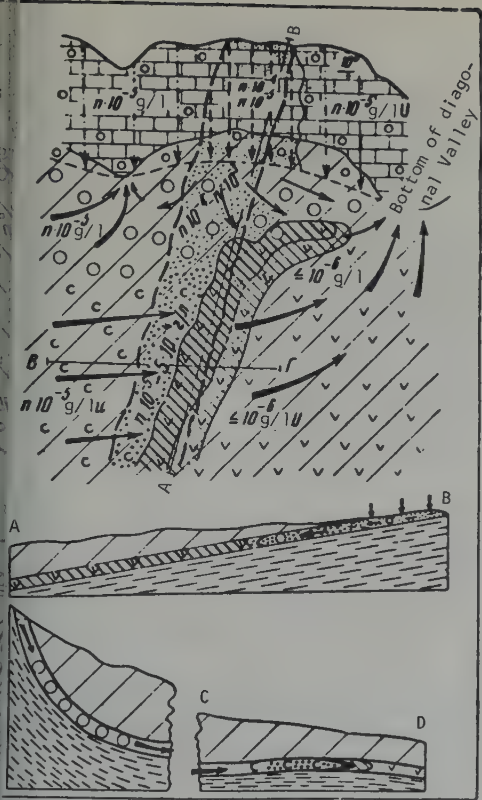
1 - content of hydrocarbon gases in water (C_nH_{2n+2}); 2 - content of hydrogen sulfide and its dissociation products (H_2S); 3 - free oxygen (O_2) content in water; 4 - total mineralization (M) of water; 5 - oxidation-reduction potential (Eh) of water; 6 - uranium content in waters of ore areas (U); 7 - uranium content in waters outside the mineralized body; 8 - radium content in waters of ore areas (Ra); 9 - radium content in waters outside the mineralized body; 10 - direction of flow of formation waters; 11 - boreholes; 12 - ore-bearing interval; 13 - petroleum trap (information on waters surrounding the trap, beyond the cross-section, is given for the oil interval); 14 - vigorous oxidation of rocks by free oxygen (high oxidation conditions); 15 - vigorous biochemical oxidation of the abundant petroleum organic matter and its products with the generation of CO_2 and H_2S reducing conditions); 16 - geologically long changes in organic matter as the result of a slow, deep water exchange (high reducing conditions).

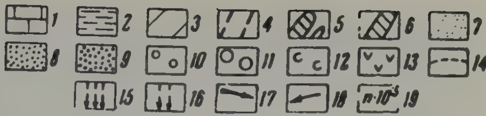
according to N. P. Kostenko) is worth mentioning. Following a considerable erosion of the anticlinal crest, at an angle to the strike of beds, the pre-existing ore zone was dissolved (Figure 3) not only by waters percolating to the limestone bed from the local high but also by high-pressure artesian waters flowing from feeder areas along the range slope (pressure gradient, 0.03 to 0.08; water mineralization, 0.5 to 2.0 gm/liter).

The uranium mineralization is dissolved first in zones with free oxygen present in their waters.

In intensively leached limestones, limonite is developed as a result of the oxidation of pyrite and other minerals, while more abundant uranium-bearing vanadates (along with "thin-spread" ones) are often formed from uranium oxides, above the water table. Dissolution takes place in deeper reaches, as well, in the absence of free oxygen in waters and, naturally, without the formation of uranium-bearing vanadates and limonite. This process is effected not only by carbon dioxide — nitrogen waters whose Eh ranges from 250 mv to zero, but also by the presence of small amounts of hydrogen sulfide (up to 10 mg/liter) in formation waters with a negative Eh, up to -50 and possibly -100 mv. Such a mobility of uranium is connected with a higher carbon dioxide content in waters (100 to 300 mg/liter CO_2), brought about by a biochemical oxidation of organic matter. Most of this organic matter has already been broken up in this zone of solution of uranium oxides in the absence of oxygen, leaving behind strongly bleached limestones. Carbon dioxide, generated in this process, promoted an intensive solution of limestones (numerous vugs, caverns, and suture-stylolitic contacts).

In the further progress of formation waters (oxygen-carrying and oxygen-free) enriched in uranium, the oxidizing conditions changed rapidly to strongly reducing conditions because of the abundance of organic matter (locally in oil films; Eh of waters, -50 to -250 mv), with uranium, after a short migration, reduced and precipitated as uraninite and nivenite. The latter is closely associated with solid bitumen having a very high C/H ratio (I. G. Chentsov, 1955). The infiltrated formation waters in this precipitation zone (also with a rather low over-all mineralization of 0.5 - 2.0 gm/liter) picked up





1 - limestone; 2 - underlying artesian water-bearing rocks; 3 - overlying artesian water-bearing rocks; 4- boundaries of an earlier zone of uranium mineralization; 5 - present position of the ore zone; 6 - same but with a lean mineralization; 7 - area of development of vanadates (locally abundant), abundant iron hydroxides, etc.; 8 - area of development of iron hydroxide, uranium-bearing vanadates (mostly lean), and remains of sulfides and the pitchblende — nivenite mineralization; 9 - area of development of unoxidized sulfides and very lean remnants of the pitchblende — nivenite mineralization; 10 - zone of abundant penetration of atmospheric oxygen, above the water table; 11 - zone of penetration of free oxygen below the formation waters in limestone; 12 - zone of oxygen-free formation waters, rich in CO_2 and often in H_2S and poor in CH_4; 13 - zone of enrichment of formation waters in hydrocarbon gases, organic matter, CO_2, and often in H_2S; 14 - water table (on the top of limestone; 15 - direction of flow of periodically infiltrating waters enriched in uranium, in limestone; 16 - same for "background" waters; 17 - present direction of flow, in limestone, of abundant formation waters from the adjacent range; 18 - same for water arrriving from the local topographic high; 19 - uranium content in formation waters, in gm/liter.

GURE 3. Redeposition of uranium in a bituminous limestone bed

drocarbon gases, as a result of biochemical idation of fairly abundant petroleum organic atter, i. e., hydrogen sulfide (up to 100 mg/ er) and carbon dioxide. The latter was re- onsible for the solution of limestone, with is process gradually diminishing beyond the e zone.

Thus a lateral "secondary enrichment" is esent with the downward one, with most of e new uranium mineralization here extending rtially beyond the earlier ore zone. There e reasons to regard this mineralization as pigenetic, having originated at an initial stage the opening up of this formerly petroliferous ticline. In this process, uranium, leached out rocks ($n\cdot 10^{-5}$ gm/liter), was carried away om a large area by weakly mineralized ground aters moving from the range and to the ero- onal window. The precipitation was local, fected by petroleum and its products, and the anium content dropped from $n\cdot 10^{-5}$ down to 10^{-7} gm/liter. This process took no less an 100,000 years, with the flow of ground ater to the precipitation zone at a rate not wer than 3 liters/sec.

This phenomenon of secondary uranium en- chment as regenerated nivenite and uraninite has been noted in some uranium-coal deposits (Figure 4) located on the range slope and associated with lentils of high-ash, pyritic brown coals in arenaceous and argillaceous rocks. This sequence is gathered up into folds and cut by faults. Water, infiltrating into coal and sandstone beds on the mountain slope, circulated freely and emerged down the slope, in a system of fault s, in abundant warm artesian springs (up to 30°C). In coal beds above the artesian waters, the seepage waters became sulfate to acid and vigorously leached the uranium. Below the artesian waters, these waters were neutralized, with a resulting deposition of uranium as the effect of organic matter and its products, in the form of nivenite and uraninite (from $n\cdot 10^{-3}$ to $n\cdot 10^{-4}$ and $5\cdot 10^{-7}$ to $2\cdot 10^{-6}$ g/liter). The thickness of the beds affected by secondary enrichment is 70 m.

Still deeper, there are coals with low uranium mineralization, gradually changing to coals with a higher uranium content (Clark index). Considering that in the seepage zone of sulfate waters (having passed through the acid stage), waters in coal beds barren of uranium ores and in adjacent pyritic sandstones contain $n\cdot 10^{-5}$ to $3\cdot 10^{-4}$ gm/liter uranium as against merely $(1\text{-}2)\cdot 10^{-6}$ gm/liter in the artesian

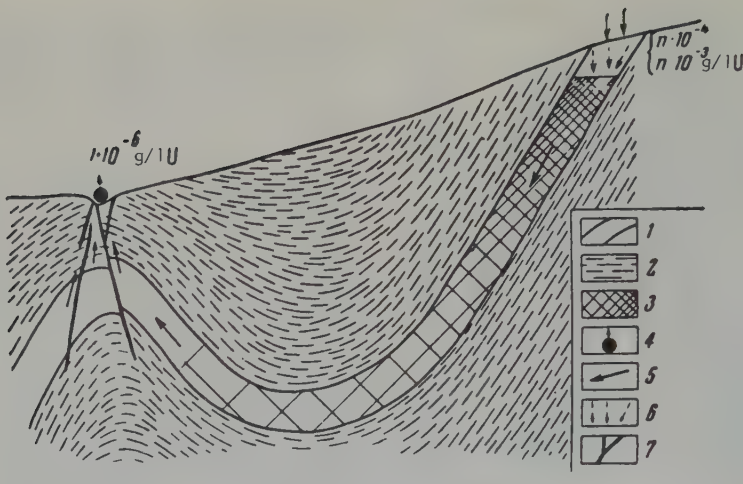


FIGURE 4. Secondary uranium enrichment in a bed of brown pyritic coal.

1 - coal bed; 2 - alternating shale and sandstone; 3 - pitchblende — nivenite mineralization, both rich and lean; 4 - warm water springs; 5 - direction of flow of formation waters; 6 - zone of periodic seepage of acid and neutral sulfate waters (leaching zone); 7 - fault trace.

springs, it can be assumed that the original uranium mineralization in the ore-bearing beds was lean, with the uranium precipitation effected by coal.

Peculiar manifestations of uranium enrichment (Figure 5) are ore bands observed in a deposit associated with coal-bearing sandstone. (This phenomenon was noted and studied by D. G. Sapozhnikov.) The bands of enriched nivenite ores (seldom as wide as several meters) occur at various depths (as much as 120 m) below the water table, in carbonaceous remnants and in gray to green-gray sandstone in contact with epigenetically oxidized brown to reddish-brown sandstones. The contact between rocks of different colors is very irregular. Obviously, waters were enriched in uranium here not only in the percolation zone but in the phreatic zone, as well, while its precipitation took place where oxidation processes were replaced by reducing processes.

Redeposition of uranium (as oxides) from ground water enriched in it by circulation through an earlier mineralization is also effected by sulfides (also after all oxygen has been expended by the water). We believe that this phenomenon was of no small importance in the redistribution of uranium in a number of hydrothermal deposits comparatively rich in sulfides. In some of them, the secondary enrichment process extended substantially below the lower boundary of the hypogene ores, thus making these deposits representative of secondary accumulations (regenerated nivenite in very small amounts of

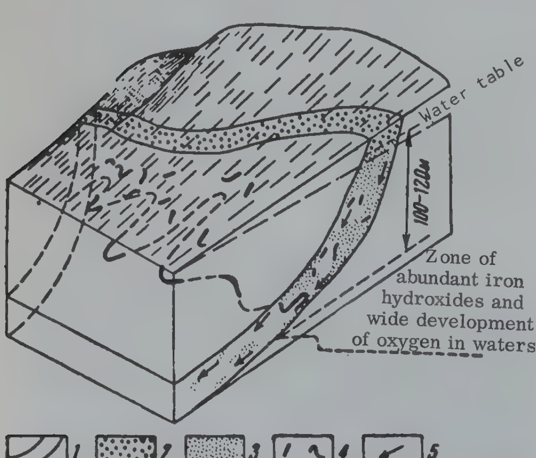


FIGURE 5. The formation of lenticular pitchblende — nivenite ores in a sandstone bed.

1 - unoxidized sandstone bed with carbonaceous remains and abundant dispersed pyrite; 2 - same, above the water table, strongly oxidized (red), locally with abundant uranium-bearing vanadates; 3 - same but less oxidized, locally with lean to seldom rich uranium-bearing vanadates; 4 - lenticular pitchblende — nivenite ores; 5 - direction of strong flow of artesian waters in the beds.

(uraninite). This process is illustrated in Figure 6.

It should benoted that the uranium enrichment here in sulfide-rich fault zones proceeded not only at the expense of uranium arriving from the upper parts of these ore-bearing structures but also as a result of lateral circulation of waters bringing in uranium from other structures, not as rich in sulfides and strongly limonitized. It is characteristic that the amount of uranium oxides decreases at greater depths. They penetrate the deepest in more intensively fractured segments; they are missing in deeper zones of fresh sulfides (free of limonite, chalcocite, and other evidence of oxidation), where oxygen-free waters circulated under natural conditions. This fact, as well as the strong enrichment of the percolation zone acid waters in uranium ($n \cdot 10^{-5}$ to $n \cdot 10^{-4}$ gm/liter), suggests that this deposit is infiltrational, having originated from a progressive enrichment in uranium, in a protracted process of leaching by sulfate waters from granite porphyries ($n \cdot 10^{-3}$% uranium) and granodiorites and deposition in the upper phreatic zone in reaction with sulfides, as nivenite and very seldom as uraninite. This process, extending even farther down, has led to the formation of industrial accumulations of uranium; such deposits are naturally richer and developed to greater depths in intensively fractured segments of sulfide veins.

In a secondary enrichment, as a rule, the bulk of redeposited uranium is represented by regenerated nivenite, with uraninite being merely of mineralogic value. However, uranium is developed widely, in places, in incrustations and veins of massive pitchblende, 5 to 7 mm thick. This has been observed in deposits associated with zones of crushing in a massif of acid intrusives (Figure 7). This massif contains many xenoliths of sedimentary rocks still carrying citumen (0.003 to 0.02% in xenoliths; 0.005 to 0.1% in the enclosing rocks). In zones of crushing, intrusive rocks and xenoliths are strongly fractured and marked by a high permeability; there is some hydraulic connection between the zones. These zones, and the adjacent rocks to a smaller extent, carry iron disulfides in very densely dispered incrustations and locally in veins, the veins being more abundant at the zone intersections with sedimentary xenoliths and in their vicinity.

Under natural conditions, prior to the opening-up of these deposits by mining, pitchblende — nivenite ores were developed here below the water table. Conspicuous is the association of a leaner mineralization with the intersections of crushed zones and sedimentary xenoliths and a short distance away from them. The vertical mineralization interval is comparatively small, with the ores becoming leaner with depth, until the uranium mineralization disappears. At the time of the opening up, phreatic waters in the ore-bearing zone were low in uranium and carried H_2S and CH_4 (from organic matter in the xenoliths); their Eh was negative. All this points to the presence of strongly reducing conditions in this part of the intrusive massif.

Located above the pitchblende — nivenite zone (between the present and the older water tables) is a zone of strongly leached (bleached) ore-bearing rocks with very lean remnants of pyrite and locally with small amounts of phosphates and silicates. Still higher up is a zone of very strong uranium leaching (pelitization and bleaching of rocks), with the uranium content concentrated in crushed zones and in large volumes of adjacent rocks lower than in slightly altered varieties of intrusive rocks (uranium loss, 20 to 70%).

After the water table in the artifically aerated zone has been lowered by mining, very acid sulfate waters (pH = 1 to 3) with an uranium content of $n \cdot 10^{-2}$ to 2 gm/liter seep through periodically.

Obviously, a later process of secondary enrichment took place under natural conditions in this deposit, wherein not only uranium of an earlier mineralization but that leached by acid waters out of intrusive and some sedimentary rock xenoliths came from above.

The intensive hypergene processing of these rocks (strong pelitization, solution cavities, bleaching) along fault zones and in their upper part, along with the presence of vary acid waters in the artificial seepage zone, suggest that acid solutions seeped through periodically, in the past, in the aeration zone above the water table (because of oxidation of iron disulfate). This consideration, together with the considerable impoverishment of these rocks in uranium, suggests in its turn that the uranium in this deposit has been leached by acid waters out of the intrusive and in part out of sedimentary rocks throughout a large vertical interval; it was then probably concentrated below the water table, because of its reduction by organic matter of the xenoliths (hydrogen sulfide etc.). This explains the absence of mineralization away from the xenoliths. Originally, with the high water table, a lean uranium mineralization emerged; then, as the water table went down, the mineralization became richer because of redeposition of the upper portion of the earlier concentrations and a progressive leaching of uranium out of rocks in the growing oxidation (aeration) zone.

Commercial concentrations of uranium originate not only in the redeposition of uranium leached by ground water out of an earlier mineralization; they are formed also as a result of local precipitation from ground water which received uranium from the water-bearing rocks. Convincing evidence of that is provided first of

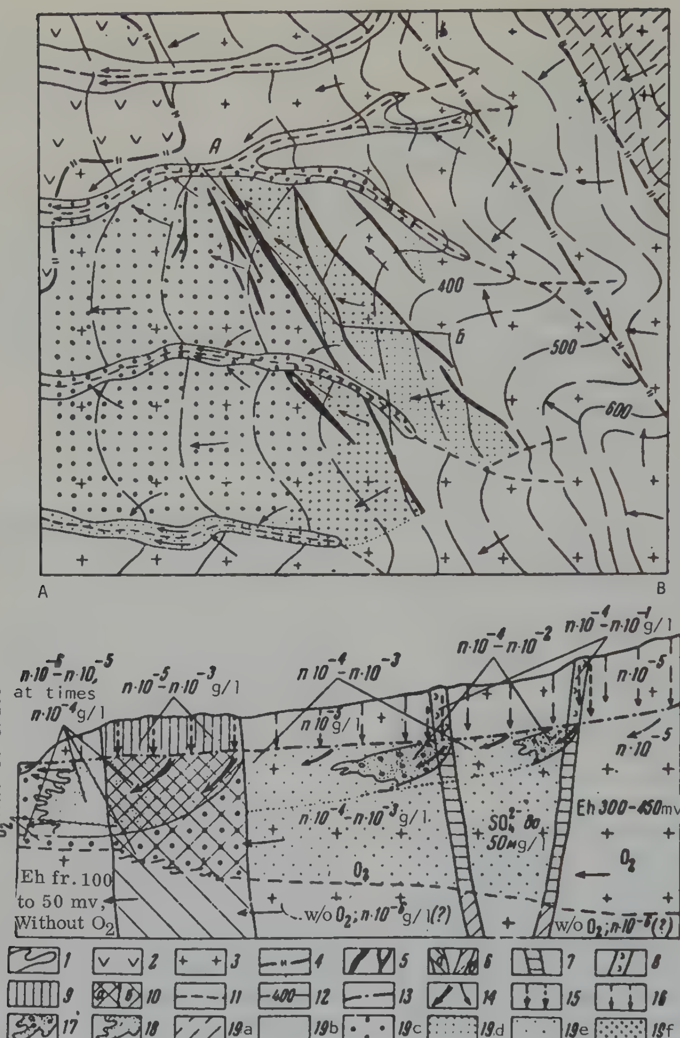


FIGURE 6. Movement of ground waters and the distribution of uranium in them under natural hydrodynamic conditions

1 - alluvium; 2 - extrusive quartz porphyry; 3 - granitoids; 4 - large fault; 5 - zone of ore mineralization; 6 - its deep part with unoxidized hypogene minerals (without limonite, chalcocite, etc.) and with a standard uranium content (Clark index): a - quartz-barite-carbonate with abundant pyrite and other sulfides; b - quartz-barite with some lean sulfide mineralization, locally with carbonates; 7 - part of zone containing nivenits mineralization subjected to intensive solution by oxygen-bearing waters; 8 - upper part of zone with occasional development of uranium-poor micas; 9 - upper part of zone with a rich to lean mica mineralization; 10 - part of zone with regenerated nivenits, chalcocite, and a moderate amount of limonite; a - zone of downward and lateral enrichment; b - zone of lateral enrichment; 11 - lower boundary of limonite, chalcocite, regenerated nivenite and other hypergene formations; 12 - isopeistic lines on the natural flow of waters in fractures; 13 - the level of such waters; 14 - their direction of flow; 15 - direction of periodically seeping waters in the aeration zone, anomalously enriched in uranium, sulfate ions, and other components; 16 - same for "background" neutral waters in enclosing rocks; 17 - extent of normal waters periodically surging up in the phrenetic zone and enriched in uranium, sulfate-ion, and other components, at the expense of the aeration zone waters; 18 - same but with waters poor in uranium, especially at their emergence from the ore zone; 19 - uranium content in waters of fractured grounds, in gm/liter: a - $5 \cdot 10^{-6}$ to $3 \cdot 10^{-5}$; b - $n \cdot 10^{-5}$; c - $n \cdot 10^{-6}$ to $n \cdot 10^{-5}$, at times $n \cdot 10^{-4}$; d - $n \cdot 10^{-4}$; e - $n \cdot 10^{-4}$ to $n \cdot 10^{-3}$; f - $n \cdot 10^{-4}$ to $n \cdot 10^{-2}$.

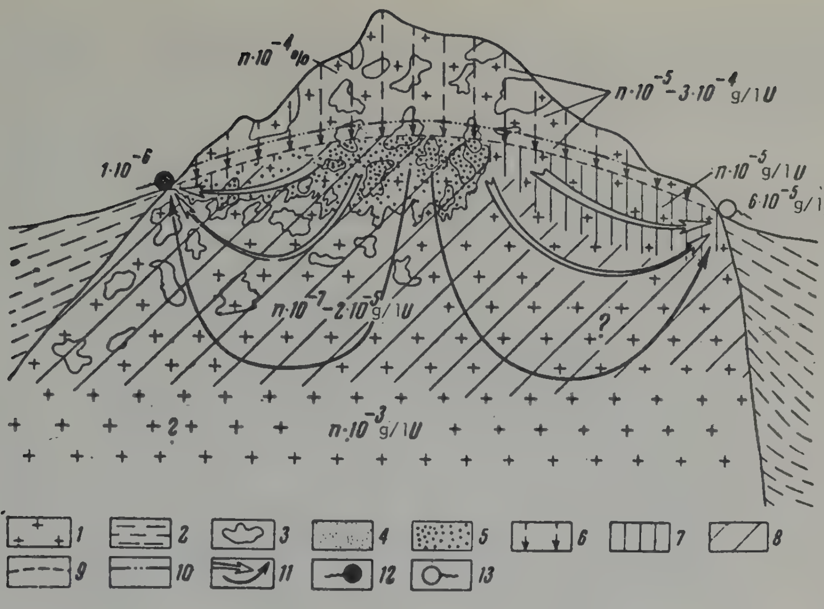


FIGURE 7. Formation of infiltration deposits in a shattered zone cutting a massif of acid intrusive rocks.

1 - acid intrusives, $n \cdot 10^{-3}$% uranium; 2 - bituminous shale and other sedimentary rocks (0.005 to 0.1% citumen content); 3 - inclusions of sedimentary rocks in bitumen; 4 - very lean uranium mineralization represented by nivenite, uranophane, dense pitchblende; dense dots rich mineralization; 5 - sparse dots, lean mineralization; 6 - zone of intensive leaching of uranium and earlier ore mineralization; 7 - extent of penetration of free oxygen into the upper phreatic zone; 8 - region of circulation of waters with H_2S, CO_2, and hydrocarbon gases; 9 - present water table; 10 - water table at the time of formation of the 2nd terrace above flood level; 11 - direction of ground-water flow; 12 - springs of H_2S water; 13 - springs of O_2 water.

d by hydrogeochemical phenomena, such as e enrichment of oxygen waters in uranium, up n· 10^{-5} to n· 10^{-4} gm/liter, in their movement through rocks with a high normal uranium ontent (Clark index) (and up to 5· 10^{-3} in eserts); the extent of its precipitation from aters under natural conditions, as an effect of educing agents (up to n· 10^{-8} gm/liter in the resence of hydrocarbons; and other facts. any geologists have come to this conclusion s a result of their rexperience in exploring r uranium deposits associated with pervious edimentary rocks containing organic matter.

A substantial enrichment of pervious rocks uranium, as an effect of ground water, and specially the formation of commercial conentrations of an epigenetic type, calls for a oincidence of the following conditions: a) the resence of a considerable area of rocks with high uranium content (Clarke index) (n· 10^{-3}% d somewhat higher, to guarantee n· 10^{-5} gm/ ter and higher in water); the conditions are nsiderably less favorable at a normal content · 10^{-6} gm/liter and less in water); b) this uraum-bearing facies, being porous, should conitute a water carrier; c) in the course of a geotectonic uplift (hydrogeologic opening up) of the area, the uranium-bearing facies should fall completely or partially in the environment of a long and free circulation of waters which vigorously leach out the uranium (waters with free oxygen or oxygen-free waters with a positive Eh); d) a sufficiently rapid change from reducing to strongly oxidizing conditions along the path of such waters in the uranium-bearing facies or in other rocks beyond it, i. e., rocks epigenetically colored pink, red, brown, and other hues or else bleached (as a result of oxidation of organic matter) giving place to green-gray, gray, and black rocks. At times uranium goes into solution in one aquifer and is precipitated in another through which waters enriched in uranium pass in the process of circulation. Its precipitation as a result of diffusion (and percolation of water) from an aquifer into adjacent slightly permeable rocks, rich in reducing agents is also possible. Because of a counter diffusion of the latter, uranium is precipitated usually at the contact zone of water-bearing rocks.

More favorable for ore epigenesis are areas where the infiltration of waters occurs during a great deficiency in atmospheric precipitation,

and where the seepage zone waters, and consequently the phreatic, are marked by a slightly [5] to much higher salt content (from a few to tens of grams per liter) and by a similar uranium ($n \cdot 10^{-5}$ to $n \cdot 10^{-4}$, in places up to $5 \cdot 10^{-3}$ gm/liter).

A good example of the strong localization of uranium in the process of downwarp circulation of artesian waters are uranium deposits in permeable sedimentary rocks, and the marginal zones of the high slopes of artesian basins (Figure 8). In some of them, the pitchblende—nivenite is associated with beds of a friable sandstone. Exploration geologists have demonstrated convincingly that gray varieties of pitchblende—nivenite are bodies (bedded deposits) are located along the lower boundary of limonitization abundantly developed in such beds (Figure 8). In plan, this boundary is jagged and runs from

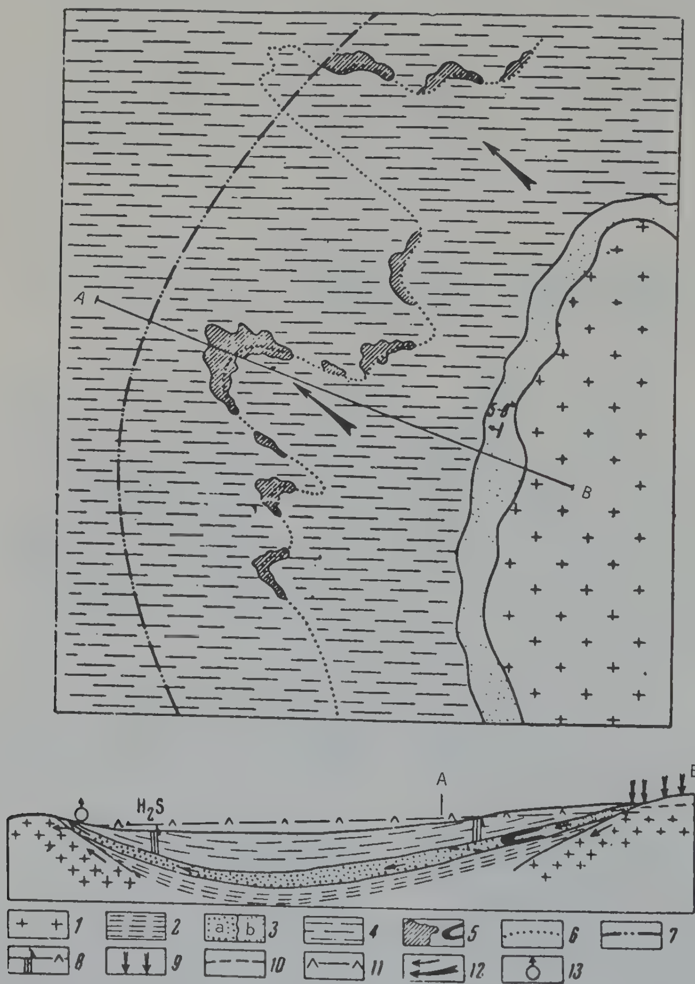


FIGURE 8. Generalized map and cross section, illustrating the distribution of uranium ore bodies in a sandstone beds, in the change from strongly oxidizing to reducing conditions (for uranium)

1 - crystalline rocks containing water in fractures; 2 - underlying impermeable sedimentary rocks; 3 - porous, ore-bearing waters of sandstone; a - gray sandstone with organic matter; b - strongly oxidized brown sandstone; 4 - overlying impermeable and other sedimentary rocks; 5 - ore body; 6 - lower boundary of intensive limonitization in sandstone; 7 - assumed lower boundary of an earlier oil or gas field; 8 - well measuring the hydrostatic head of the Pedi; 9 - seepage area of waters feeding the Pedi; 10 - water table; 11 - piezometric water level in the artesian area; 12 - direction of water flow; 13 - springs in the discharge area of artesian waters on the lower limb of the basin.

dreds of meters to a few kilometers from ore-bed outcrops. In other words, the in-sive oxidation of sandstone has penetrated e considerably below the formation water el (150 m, vertically, in places 200 m). In interval (Figure 9), waters carry free oxy- and relatively high amounts of uranium; r Eh is above 300 (250) mv. Below this ndary, rocks are gray to green-gray, and ry organic carbon and finely dispersed sul-s (only a grace of these reducing agents e been found in oxidized sandstones); Eh of ers, here, is negative (-50 to -200 mv) and uranium content is low (1-3)$\cdot 10^{-6}$ gm/liter.

The change from oxidized rocks to the gray s is rapid, occurring usually over a distance asured in centimeters to a few meters, less nmonly a few tens of meters.

In these ore deposits, the ore beds are rked by two features in addition to their uni-m and fairly abundant saturation in pyrite d organic matter (expressed in inclusions of id bitumen, a few millimeters in size). First, h the oxidized and gray ore-bearing beds out-le the ore zone have a higher uranium content 10^{-3}%), than have the granites which underlie them. For this reason, and also because of the hot and dry climate, the uranium content in waters of the sandstone, and in waters abundantly feeding them from the granites, is higher than normal, amounting to n$\cdot 10^{-5}$ to 3$\cdot 10^{-4}$ gm/liter in this outside zone. Secondly, these sandstones, because of their relative uniformity and friability, are marked by a uniform permeability (especially along the bed). This is conspicuous in mining works where water seeps from the ore-bearing bed uniformly throughout the rock face. We believe that it is this uniform permeability that has determined the form of uranium ore bodies, a compressed crescent moon, in a vertical cross section (sacks, rolls). This is explained by the fact that, in the flow through a homogeneous layer, the velocity of flow decreases from its middle to the top and base (Figure 9). Because of that, the oxidation process, and consequently the precipitation of uranium have penetrated deepest in the middle part of the bed; because of the larger volume of water which flowed through, richer ores have been deposited here (and a larger amount of uranium).

The origin of ore bodies having such forms has also been prompted by uranium diffusion toward the top and base of the bed and beyond it;

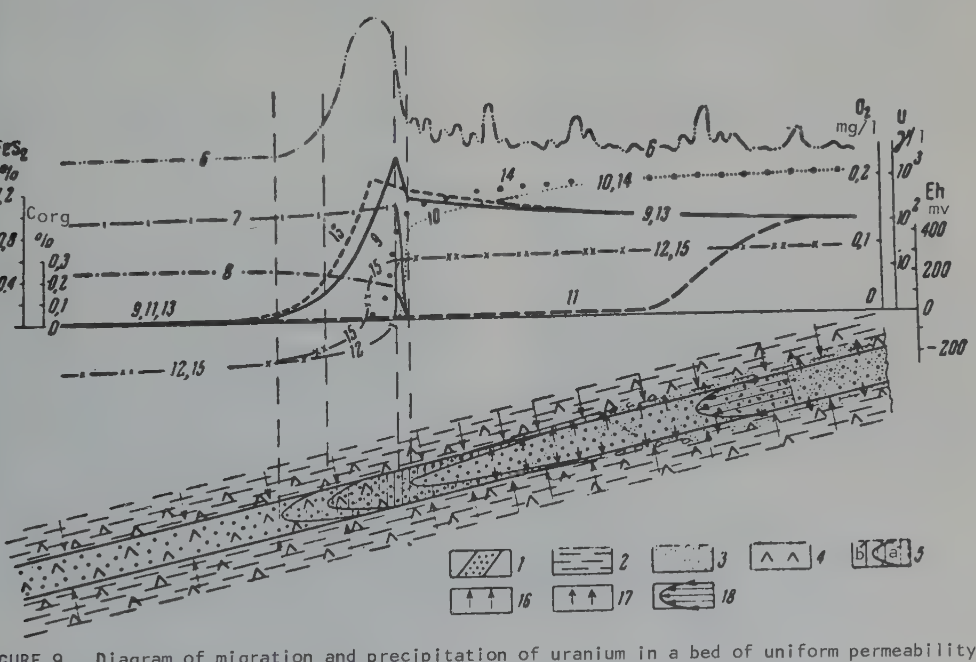


FIGURE 9. Diagram of migration and precipitation of uranium in a bed of uniform permeability

1 - porous sand bed; 2 - shale and silt; 3 - strongly oxidized brown rocks; 4 - gray to green-gray rocks; 5 - uranium mineralization; a - rich; b - lean. Content in rocks of the middle part of bed (after A.N. Shevnin; M.A. Alekseyava, et al): 6 - uranium; 7 - sulfides; 8 - organic carbon. Content in waters of the middle part of bed (under natural conditions); 9 - uranium; 10 - solution oxygen; 11 - uranium in one of earlier periods of the formation of a leaner mineralization; 12 - Eh of waters in middle part (under natural conditions); 13 - uranium content in the formation water flowing to the well from all directions; 14 - solution oxygen content in these waters; 15 - their Eh [13, 14, 15] after A.A. Smirnov, A.K. Glazov, K.V. Kernosova, et al); 16 - direction of diffusion of CH_4 and other hydrocarbons; 17 - direction of uranium and oxygen diffusion; 18 - velocity vector for the water direction.

as a result, a lean mineralization has been developed in sandy shale above and below the ore bed. A counter diffusion of methane and other reducing agents, too, promoted the formation of "sacks".

This uniform permeability is one of the causes of the considerable uranium concentration in these sand - sandstone beds. In these aquifers, with their uniform porosity and the absence of water-conducting fractures, and also because of the even distribution of reducing agents is them (organic matter, sulfides, ferrous iron), the change from an oxidixing to a reducing environment always took place over a short interval, while the oxidation proceeded uniformly throughout the entire aquifer. If the sandstones were denser and with fractures of various permeability, the oxidation would have affected the bed very unevenly, with the corresponding deposition of uranium taking place over a longer distance of the downward water circulation. The pitchblende — nivenite mineralization, as well as limonitization, would have had a spotty distribution; being "spread-out" over a considerably larger area, it might not be of commercial interest. The "spreading-out" of an epigenetic uranium mineralization occurs in many rocks with an uneven permeability (heterogeneous composition of clastic material, rapid change of facies, change in the intensity of fracturing, etc.). The results are similar where reducing agents are unevenly distributed in an aquifer (in patches, small lenses, etc.).

The abundant concentration of uranium has also been promoted by the absence of a higher than the normal vanadium content in the rock and water; as demonstrated in a number of ore deposits, vanadium somewhat hampers uranium migration in the zone of circulation of oxygen-bearing waters, because of the formation of uranium-bearing vanadates (especially in the seepage zone, considerably below the water table [sic]). It took considerable time to form such deposits (part of the Neogene and the Quaternary).

To understand the origin of these deposits, it must also be taken into account that anticlines on whose limbs they are located were closed at one time and probably contained stores of petroleum or hydrocarbon gases, as is true now in deeper structures of the region.

Formed first was a lean pitchblende — nivenite mineralization, a short distance away from the ancient outcrops of sandstone and granite. Circulating waters of the sandstone, because of the latter's rich dispersion pyrite and high uranium content (Clark index), were strongly enriched ($n\cdot 10^{-5}$ to $3\cdot 10^{-4}$ gm/liter); the additional and abundant water from underlying granite also was rich in uranium. The sandstone beds contained more than enough precipitating (reducing) agents, newly liberated from the oil and gas deposits.

The process of migration (and uranium deposition) were intensified and then slackened depending on the intensity of the range uplift. The latter's ore mineralization was continually displaced toward deeper levels, and was progressively enriched in uranium. As the limonitization occurred deeper in the section, the peripheral (inside) parts of the mineralized body were dissolved (oxidized) and the dissolved uranium was redeposited nearby, as oxides. This process is still going on. Not only is the uranium abundant in circulating waters as a result of dissolution (oxidation without forming secondary usanium minerals) of the entire peripheral zone of the ore deposits deposited; also dissolved is the uranium previously captured from the remains of an earlier mineralization,. preserved here and there along the dip, as well as uranium leached out of sandstone and granite ($n\cdot 10^{-5}$ to $3\cdot 10^{-4}$ gm/liter).

It appears that limonitization and the corresponding solution of the uranium mineralization have penetrated locally below the oil and gas closure of ancient anticlines; as a result, the ore deposit uranium was dispersed in such areas, because of the lack of organic matter in beds below this closure. Lentils arranged one above another and pressed toward the top and the base of the bed were observed in a number of ore deposits; they are not interconnected even in the gray sandstone zone. One-layer lenses are present also at the top of the bed. Inasmuch as there are, at the present time, no detailed data on the distribution of reducing agents in the ore-bearing bed, we can surmise that in these areas, the amount of biologically active organic matter in the ore bed itself was inadequate to bring about an abrupt change in the conditions necessary for uranium precipitation. In the central part of the bed, ground water without oxygen may maintain a positive potential and keep the uranium in solution. Uranium deposition proceeds but gradually, throughout the large circulation interval in gray sandstone. At the contact with artesian aquifers, on the other hand, at the base or at the top of a bed, reducing conditions become better expressed because of the diffusion of methane and other hydrocarbons in their water, which is what caused the precipitation of uranium.

In addition, a somewhat different epigenetic ores (oxides) have been observed in sedimentary rocks, wherein the factor precipitating uranium from artesian water is a coal lens in an arenaceous to argillaceous interval. As long as such a lens is sufficiently large, the uranium concentration in this "trap" attains commercial value. Such an origin of ores is suggested by the fact that waters of granite and sandstone leach $n\cdot 10^{-5}$ to $3\cdot 10^{-4}$ gm/liter uranium out of rocks in the source area, while they carry only

…$^{-6}$ gm/liter uranium in the submerged part …e bed, below the ore deposit.

…he examples described in this paper com…e but a small portion of the variety of oc…ences of uranium deposited from ground …r because of the effect of reducing agents.

…t is possible that this reduction of uranium by …nic matter and its products (CH_4 etc., H_2S, …) is also one of the main factors in the for…ion of metamorphic and hydrothermal ore …osits. Indeed, some of them are associated … carbonaceous, bituminous, and other rocks …rying organic remains. Many such rocks are …ted below the ore deposits, at some depth, …away from them laterally, so that hydro…bons and H_2S could migrate toward the areas …re formation. Moreover, organic matter, …h as bitumens, is present (up to 0.2%) in …st rocks studied for that purpose (oral com…nications by G. A. Kuritsina, S. N. Ivanov, … K. K. Matveyev, 1947). In the period of …culation of uranium-bearing solutions, these …umens, assisted by the action of the sulfide … (S^{2-}, HS^-) and at times of ferrous iron …$^{2+}$), could have caused an additional reduc…n and precipitation of uranium as well as the …mation of H_2S and sulfides, contemmorane… with the uranium oxides.

What has been said above should be regarded …rely as a working hypothesis.

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BRIEF COMMUNICATIONS

BALAGAN-TAS, AN EARLY QUATERNARY VOLCANO[1]

by.

M. S. Argunov and S. I. Gavrikov

The Balagan-Tas volcano is located on the right bank of the Moma River, a right tributary of the Indigirka.

This volcano is of great interest because of its location in the Yano-Kolymsk Mesozoic fold belt where younger Quaternary volcanism is expressed very poorly. As of now, only two Quaternary volcanoes are known in the northeastern part of the U. S. S. R: the Anyuy described by Ye. K. Ustiyev [3], and the Balagan-Tas.

The Balagan-Tas was first visited by geologist V. A. Zimin, during a 1939 geologic reconnaissance. In 1949 it was briefly described by A. P. Vas'kovskiy, from aerial photographs [1], and by P. F. Shvetsov [4], in 1946. However, no detailed description has been made.

The information given in this paper is the author's summary of the 1958 field work by M. S. Argunov, combined with earlier data.

The Balagan-Tas volcano is located within the Momo-Zyryansk Cretaceous trough [2]; together with its protruding foothills, it occupies an area of 1.8 km^2, with an area of lava flow estimated at 4 to 5 km^2.

The trough is filled with Lower Jurassic marine and Lower Cretaceous coal-bearing lagunal and continental deposits in comparatively fat folds trending northwest to west.

These folded structures are broken up by faults trending northwest to northeast. The first ones are larger and longer; the second are shorter and younger than the first ones.

The volcano stands on a 60-m high terrace on the right bank of the Moma River (10 km. away from the river); in the vicinity of the volcano, the terrace is cut by the Balaganyky River valley (Figure 1). The terrace, marshy and overgrown by a dense forest, is dismembered by numerous small streams, some of whose headwaters reach the foot of the volcano.

The Balagan-Tas is located near the crest of a brachi-anticlinal fold of Lower Cretaceous sandstone and arenaceous and argillaceous deposits and cut by a series of North-northeast trending faults. The volcanic center is located at the intersection of this and a latitudian trend.

This volcano is of the central type (Figure 2). It has a regular truncated cone about 300 m high (absolute elevation, 993 m) with a base diameter of 1000 to 1200 m. Its lower slopes, overgrown by low brush and larch, rise at 20 to 30°, with the southwest slope somewhat gentler (up to 20°) than the north slope.

The northwest slopes are cut by two erosional ravines; in the southwest slope a 20 to 30 meter trough-like trench with steep sides, runs from the crater to the foot, it is probably a former lava flow channel now draining spring and rain water from the crater.

The crater itself, poorly preserved, has a dish-like form. Its outside diameter is 200 m with an inside diameter of 120 to 130 m.

The maximum depth of the crater is 40 m; the north rim stands higher than the south which is cut through by a gap. The crater bottom is partly sodded up and covered by red-brown weathered materials.

The upper part of the volcano is made up of chiefly highly uesicular, black, pumice-like lavas of basalt composition, interbedded with red to purple-red baked slag of the same composition.

The lower slopes are poorly exposed. Judging from the rare outcrops, the rocks consist partly of black pumice-like to baked red lavas.

[1] Rannechetvertichnyy vulkan Balagan-Tas.

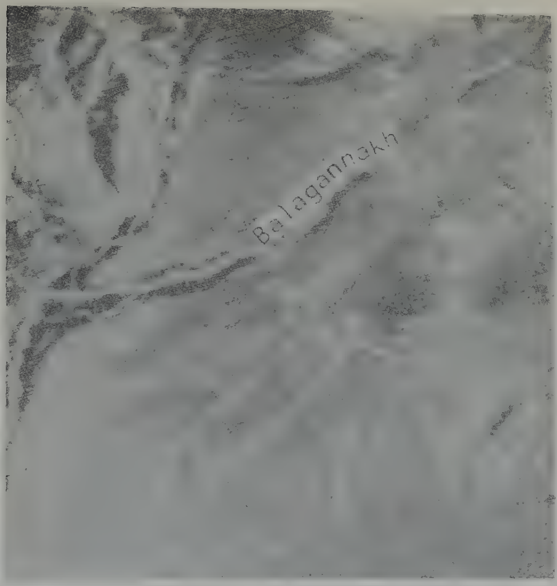

FIGURE 1. Volcano Balagan-Tas. Regional Aerial photograph. Dashed lines are identified fault traces. Scale, 1:88,000.

The black pumice-like lavas are full of bubbles (Figure 3), and of low enough specific gravity to float on water. The cavities are usually spherical, less commonly oval to oblate, up to 1 cm. in diameter. They are formed by black obsidian, crystals and fragments of pyroxene, and gas bubbles. Obsidian is locally crystallized in haphazardly oriented plagioclase microliths.

The red and purple-red lavas are of the same type as the preceding ones; they show a distinctive splintery, cavernous structure. The abundance of uesicles and the slag-like aspect of

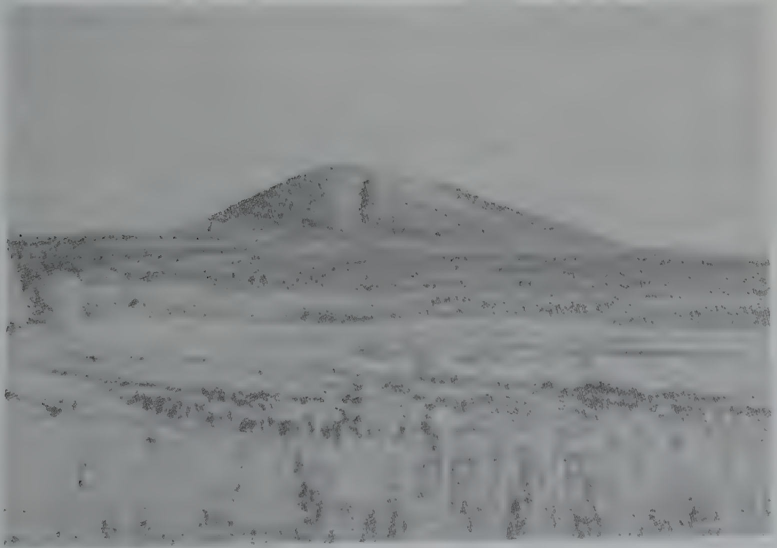

FIGURE 2. Volcano Balagan-Tas as seen from the Balagannakh River.

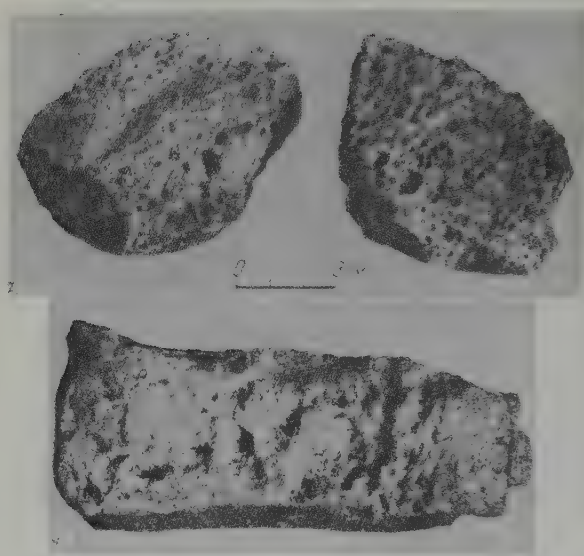

FIGURE 3. Pumice-like basalt lava

a - black; b - red, backed

these lavas suggests a generally high gas content of solidifying melt.

Unlike the Anyuy volcano [3], there were no mighty melt blows, here, which could have formed tubular vents.

Volcanic bombs, comparatively scarce, are found at the foot and along the slopes of the volcano. Their dimensions range from 2 to 30 cm. They present usually elongated, dense, fused bodies. Common among them are bent and twisted forms, originating by rotation during their flight.

In composition, the volcanic bombs, too are chiefly basaltic. Under the microscope, they display distinct fragments of pyroxene crystals, an ore mineral (ilmenite), plagioclase microliths, and partly recrystallized glass.

The area of distribution of lava and loose erupted material is difficult to ascertain because of the marshy terrain. The presence of lava fragments on the terrace and in the Balagannakh alluvium suggests that a thin lava sheet (a few to ten meters) probably partially covered this terrace, especially south and southwest of the volcano.

The age of this volcano is probably early Quaternary. The reasons for this assumption are as follows: a) the volcano's position on a 60 meter Quaternary terrace of the Moma River; b)the finding of spores and pollen in the fused loam of a volcanic bomb, which allowed P. R. Shvetsov [4] to assign it to the post Pliocene.

In conclusion, the following statements are offered:

1. The Balagan-Tas volcano is of the central type and has developed in an area of intensive northeasterly faulting.

2. A poorly expressed stratification of the volcanic cone (altogether lacking locally) suggests the importance of explosions in its formation, alternating with periods of comparative quiescence and lava flows. The explosions were probably relatively weak, because pyroclastic material is subordinate in the cone section; moreover, it has not been scattered very far away from the cone.

3. The dimensions of the volcano and the area of its lava flow suggests a short active period, occurring in the Quaternary. This is corroborated by spore and pollen analysis and by the position of the Balagan-Tas on a Quaternary terrace.

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SOME FEATURES OF THE BEHAVIOR OF INDIUM IN DEPOSITS OF DIFFERENT AGES[1]

by
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In his analysis of the specific aspect of different cycles of the development of the earth's crust, V. I. Smirnov [7] made a general statement to the effect that "hydrothermal deposits are missing in rocks of the Archean age, very poorly represented in rocks of Proterzoic and Caledonian age, very vigorous in rocks of Hercinian age, and continue to be prominent in rocks affected by Mesozoic and Alpine metallogenic epochs." He includes here deposits of copper, polymetals, antimony, and tin.

In natural processes, indium is a companion of zinc and tin. Because of that, it is quite reasonable to anticipate the appearance of concentrations of indium in Hercinian, Mesozoic, and Alpine metallogenic cycles characterized by maximum accumulations of zinc and tin. Indeed, as early as 1941, N. M. Prokopenko [4] while studying the behavior of indium in various metallogenic cycles of the U. S. S. R., has determined that this element is most common in deposits of the Hercinian metallogenic cycle. At the same time he stated, despite the extremely poor state of knowledge of younger deposits (Mesozoic and Alpine), that they may turn out to be enriched in indium.

[1] O nekotorykh osobennostyakh povedeniya indiya v mestorozhdeniyakh razlichnogo vozrasta.

Listed in Table 1 are the numerous data extant on the intensity of indium development, along with its content in various types of indium deposits of different ages (Caledonian, Hercinian, Mesozoic and Cenozoic). In determining the relative strength of the indium showing in a metallogenic cycle, it is important to know how well the several types of indium deposits are developed. For this reason, we have compiled Table 2 which shows the time distribution of indium deposits.

These tables demonstrate adequately that in the various types of indium-bearing deposits, the intensity of the indium development and the strength of the indium concentration, vary from older metallogenic cycles to the younger.

Deposits of Precambrian and Caledonian cycles are characterized by low concentrations of indium, not exceeding 0.001%, as has been demonstrated [10] for cassiterite of high-temperature tin ores and tungsten deposits of the following types: mineralized granite, pegmatite, greisen, and quartz veins. All known deposits occur in areas of ancient shields (African, Brazilian). Higher indium content, occasionally up o hundredths of a percent has been discovered [9] in Caledonian pyrite and polymetal deposits of Scandinavia. It is of interest that in some south Norwegian deposits with 0.01 to 0.03% indium, in sphalerite, tin appears in hundredths of a percent. This is worthy of attention because such a relationship appears to be universal. For example, the Pitkyarant polymetallic skarn deposit (Baltic shield), characterized by the presence of cassiterite, also carries much indium [8] which, on the whole is not typical of ancient deposits.

Indium occurrences are more common and more diversified in rocks of the Hercinian cycle. Appearing here are cassiterite sulfide (England, Tasmania, Australia) and polymetallic tin (Germany, U.S.S.R.) deposits with a higher than average indium concentration (hundredths of a percent, in sphalerite). However, incomparably larger amounts of indium are present in ores of major polymetallic pyrite and lead-zinc deposits of the U.S.S.R., Western Europe, etc. Indium is distibuted very unevely in these deposits. It does not form high concentrations; as shown by N. M. Prokopenko [6], it occurs mostly in comparatively high-temperature deposits, while the low-temperature deposits are on the whole markedly poor in indium. This phenomenon is especially typical of telethermal lead-zinc deposits (U.S.S.R., U.S., North Africa). Hercinian pyrite, polymetallic pyrite and lead-zinc deposits are best developed in the U.S.S.R. In these deposits, indium is present most commonly in ferruginous sphalerite where its content seldom exceeds ten-thousandths to a few thousandths of a percent; another indium-bearing mineral is chalcopyrite and in places galena [3].

TABLE 1

The intensity of development of indium and its mean content in various types of indium-bearing deposits of different ages

Type of deposit	Metallogenic Cycle					
	Caledonian		Hercinian		Mesozoic and Cenozoic	
	Intensity of Development	% content	Intensity of Development	% content	Intensity of Development	% content
Cassiterite-carrying granite and pegmatite	Poor	<0.001	Poor	<0.001	Poor	<0.001
Cassiterite and tungsten greisen and quartz veins	"	<0.001	"	0.001	"	<0.001
Tin-bearing skarns	"	0.001—0.005	Typical	0.001—0.005	"	0.01 and over
Cassiterite-silicate and cassiterite-sulfide	—	—	Widely Distributed	0.001—0.005	Widely distributed	0.01 and over
Polymetallic tin	—	—	Typical	0.01	" "	0.01 and over
Tin-bearing polymetallic with sulfosalts of tin, lead, and silver	—	—	"	0.01	" "	0.01 and over
Pyrite and polymetallic pyrite	Typical	0.001—0.005	Widely distributed	0.001—0.005	" "	<0.001
Assorted lead-zinc (high temperature)	" »	<0.001	Typical	<0.001	Typical	<0.001

TABLE 2

Distribution of indium-bearing ore deposits in various metallogenic cycles

Type of deposits	Metallogenic cycle		
	Caledonian	Hercinian	Mesozoic and Cenozoic
Cassiterite-carrying granite and pegmatite	Fairly typical	Fairly typical	Poorly developed
Cassiterite and tungsten greisen and quartz veins	Poorly developed	"	Fairly typical
Tin-bearing skarn	Same	Poorly developed	"
Cassiterite-silicate and cassiterite-sulfide	—	"	Very widely distributed
Tin polymetalic	—	"	"
Tin polymetalic carrying polymetallic deposits with sulfosalts of tin, lead, and silver	—	"	Fairly typical
Pyrite and polymetalic pyrite	Poorly developed	Very widely developed	"
Assorted lead-zinc deposits (other than the deposits deposits described above)	"	"	"

In contrast to ancient folding zones, the rdium occurrences are especially plentiful and ried in Mesozoic and Cenozoic deposits (Table . This was first noted by N. M. Prokopenko , 6] who determined the distribution of indium the eastern Trans-Baykal Mesozoic metallo- nic province. Subsequently, the broad dis- ibution of this element has been recognized many Mesozoic and Cenozoic depostis of the r eastern and northeastern part of the U. S. S. R. d abroad in the Bolician ore province and some posits of the U. S. and Canada [1]. It is in esozoic and Cenozoic deposits that the relation- ip between indium and tin is best expressed. hus, while indium-carrying tin-sulfide depo- ts are comparatively rare in the Hercinian etallogenic cycle, they are very widely devel- ped in the Mesozoic (Table 2). Outstanding nong them are indium-bearing skarn tin ores, ssiterite-silicate, and cassiterite sulfide de- osits. Tin bearing polymetallic deposits with strong development of assorted sulfosalts olivia) are intensively developed in some ore rovinces.

The indium concentration in these types of eposits is, as a rule, much higher than in eir more ancient analogues (Table 1). In a umber of instances, the indium content in any of these deposits exceeds by a factor of ns of thousands the indium Clark index for e earth's crust, and reaches several tenths f a percent, as in sphalerite [2]. In addition sphalerite, indium is fairly common in alcopyrite and stannite, where its concentra- on usually amounts to thousandths or hundredths a percent, as well as in cassiterite. Collmor- ic varieties of cassiterite (wood tin) formed der the most shallow conditions are especially ch in indium (up to 1%).

The behavior of indium in other types of Mesozoic and Cenozoic deposits (Table 1) differs but little, on the whole, from that in older deposits. The only difference appears to be in a somewhat lower indium content in younger pyrite deposits (Alpine) compared with older deposits (U. S. S. R.). This is more in the nature of a general tendency rather than a well defined regularity.

This brief survey of the pattern of behavior of indium in deposits of different ages shows that there is an intensification of indium development in deposits from older metallogenic cycles to younger cycles, as expressed in higher concentrations of this element in its carrier minerals. The overall scipe of the distribution of indium sharply increased in the Hercinian metallogenic cycle, chiefly at the expense of pyrite, pyrite-polymetal deposits and zinc-lead deposits. The fairly wide distribution persists in the Mesozoic and Cenozoic deposits. The types of deposits where indium is concentrated change along with the intensity of indium development from older to younger cycles. For instance, assorted indium bearing tin-sulfide deposits with a maximum indium concentration, which had appeared in the Hercinian, were best developed in the Mesozoic and Cenozoic deposits with the younger representatives of these deposits containing the most indium.

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AN INTRAFORMATIONAL HORIZON IN THE UPPER LIASSIC VOLCANIC SEQUENCE (NORTH OSETIYA, THE CAUCASUS)[1]

by
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A thick sequence of Lower Liassic volcanics, involved in the structure of the north line of the main Caucasian anticlinorium and the north and south limbs of the Sadono-Unal'sk anticline, occupies a prominent place in the Lower Jurassic stratigraphic section of north Osetiya.

The cores of these structures are made up of the Main Range granite as well as crystalline gneiss (PCm - Pz_1), directly overlain by Lower and Middle Jurassic sedimentary volcanic rocks.

Lower Liassic volcanics are underlain by basal conglomerate and overlain by Lower to Middle Jurassic arenaceous and argillaceous deposits. The structure of this volcanic sequence is complex, and its rocks are varied [1, 2, 3, 4]. Best developed are lavas of a predominately prophyritic composition: quartz porphyrite, plagioclase and biotite-hornblende porphyrite, with subordinate dense and banded tuff, also lava conglomerate, usually motled. The extreme area inconsistency of volcanic beds precludes a more detailed classification of this sequence.

As a result of the large-scale mapping of the north Osetiya volcanics, we have identified a peculiar intraformational horizon of assorted volcanoclastic rocks.

In the north limb of the Sadono-Unal'sk anticline, this horizon has been traced from the ruins of Luar village to Tsus-Don river, a distance of 4. 5 km. There is evidence of a thin conglomerate bed in the Khod river gorge, and a 5-meter thick sandstone bed along the Zgid-Don river [2]. Thus, the intraformational horizon is exposed farther west, as well.

In the south limb of the Sadono-Unal'sk anticline, the volcanic sequence is buried under Lower and Middle Jurassic deposits thrust over it from the south. Because of that, it was impossible to trace the intraformational horizon, here. In the north limb of the main Caucasian anticlinorium, this horizon has been traced over 5 km from the Tsakhtsiri-Khokh southeastern slope to the northwestern slope of Sadon-Vtsek Mountain.

The thickness of this horizon ranges sharply along the strike, from a maximum of 40 to 50 m to a total wedging out.

Despite a certain angular unconformity, the intraformational horizon is conformable on the whole with the basal conglomerate horizon underlying the volcanic sequence. The horizon occupies a definite position in the volcanic section, approximately in its middle part, but somewhat nearer to the base.

[1] O vnutriformatsionnom gorizonte v nizhneleyasovoy vulkanogennoy tolshche. Kavkaz, Severnaya Osetiya.

n the north limb of the Sadano-Unal'sk anti-e it is underlain by a 60-m thick volcanic mber; in the north limb of the main Caucasian clinorium, the underlying member is up to m thick.

Present in the intraformational unit are as-ted conglomerate, tuffaceous conglomerate, aceous sandstone, and tuffs, with the con-merate and tuffaceous conglomerate pro-inant. In the Arkhon river area and near Luar ruins, they are represented by coarse glomerate with fragments of quartz, por-ritic lava, quartz-sericite crystaline schists, tuffaceous sandstone. Fragments of por-ritic lavas and tuffaceous sandstone are rked by their poor rounding. The poorly nded fragments of crystalline schist are ally sharply angular. The fragments' di-ntions range from 3 to 10 cm across.

The conglomerate is cemented by tuffaceous dstone consisting of fragements of quartz, gioclase, muscovite, and assorted extrusives. agments in the tuffaceous sandstone are 1 to mm, commonly cemented with a sericitic or rtzitic substance, or by a pelitic cement.

Occurring on the Tsus-Don—Arkhon water-ed and on the south slope of the Tsey Range tuffaceous conglomerates consisting chiefly porphyritic lava and tuff and quartz frag-nts. They are cemented, as a rule, with ystalloclastic tuff, acid to intermediate in mposition.

Conglomerate with black, sandy cement is st developed on the south slope of the Tsey nge; it is strongly sericitic and chloritic d contains rounded fragments of quartz and ugh fragments of light-gray plagioclase por-yrite. Somewhat less common are 0.5 to 5 cm fragments of quartzitic rocks, black rbonaceous shale, and fine-grained gray anite.

Tuffaceous sandstone is developed to a aller extent in the intraformational unit. the Arkhon river area, it is interbedded th conglomerate. This tuffaceous sandstone a dense gray rock with grains of quartz, agioclase, and black carbonaceous shale rain size, 0.2 to 0.3 cm). Its cement has en fully silicified and sericitized.

Fine ash tuff consolidated to a dense, fine-ained rock, black to dark-gray and consisting grains of quartz, plagioclase, commonly fully rbonatized, muscovite, and occasional apa-e and zircon is typical of the intraformationl it. The grains are fine, 0.01 to 0.02 mm. e cement is pelitic with fine scales of second-y sericite, chlorite and epidote. Similar ash tuffs have been observed in the Arkhon area and on the southeastern slope of the Tsakhtsiri-Khokh.

These observations have established the following facts:

1. The intraformational horizon is present throughout the entire area of the volcanic sequence.

2. Despite the peculiar character of its occurrence, the frequent wedging-out, and the sharp change in ites lithology, this horizon affords a correlation of individual sections in a detailed classification of the volcanic sequence, and allows a determination of the nature of folds formed by it.

3. Such an occurrence of this horizon militates against the G. M. Yefremov assumption of isoclinal folds within this volcanic sequence.

4. The presence of an intraformational clastic member in this volcanic section suggests that the section was not formed at a single stage; there was a short break in volcanic activity, accompanied by minor erosion, with the intraformational horizon formed as a result.

5. This horizon was formed in the littoral zone of a marine basin, with material deposited in depressions of relief formed during earlier volcanic stages. Evidence to support this statement is as follows: a) a frequent wedging out of the intraformational horizon; b) a minor angular unconformity observed between this horizon and a basal conglomerate underlying the volcanic sequence; c) the different thickness of the underlying volcanic members.

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REVIEWS AND DISCUSSIONS

FEATURES OF GERMANIUM CONCENTRATION IN COALS
(Reply to the review by V. M. Yershov)[1]

by

A. B. Vistelius

The following remarks are pertinent with re-
d to the interesting review by V. M. Yershov
. Akad. Nauk, S.S.S.R., vol. 58, no. 7,
7).

1. Coal consists essentially of two fractions:
anic (C) and mineral (Z) which turns to ash
n burning. The sum of C and Z is very
se to 100%. It follows from the properties
C and Z that the lower the C content in a
l, the higher its Z content, and vice versa.
s relationship is functional, i. e., precise.

I demonstrated in 1947 that Ge is concen-
ted in C. This conclusion was based on the
stence of a definite reciprocal relationship
ween the percentage of Z in coal and that of
in Z, i. e., the larger the Z, the smaller
Ge content, and consequently the larger the
These conclusions of mine, 12 years old,
fully acceptable to the reviewer, although
puts his own view in opposition to mine with-
any reason. At the same time, the reviewer
tes quite correctly that the correlation fac-
s between Z and the percentage of Ge in Z,
l between Z and the percentage of Ge for
al coal, have a different meaning. This is
te elementary; unfortunately, I did not em-
size it in 1947.

2. As already noted, the reviewer is quite
rect in attributing a different meaning to the
ationship of Z with percentage Ge in Z and Z
h percentage Ge in coal. The important
ng is that the reciprocal relationship be-
en Z and Ge in Z means that Ge is concen-
ted by the organic material of coal; and the question is whether all or part of C is the concentrating agent for Ge. If there is no appreciable relationship between percentage of Ge, which is the case, according to the reviewer, and of which we have no other information, as explained below, we have no reason to assume that Ge is concentrated by C. After having cited the lack of proof for a reciprocal relationship between percentage C and Ge in coal, the reviewer jumps to a conclusion diametrically opposite to the one which is warranted. This surprising conclusion, not warranted by the substance of the review, coincides with mine, as of 1947. It is a correct one but, coming from V. M. Yershov, it is utterly unfounded.

3. At the present time, we have two correlation factors. One characterizes the relationship between percentage Z and Ge in Z; the other does the same for Z and Ge in coal. An analysis of the geochemical meaning of these factors (unfortunately neglected by the reviewer) leads to the following conclusions. Germanium in coal is concentrated by a part of the organic matter. The magnitude of this part is in direct relationship to the total organic content in coal. If this is true, a ration is possible at which a low reciprocal relationship relationship between percentage Z and Ge in coal, and a simultaneous high reciprocal relationship between percentage Z and Ge in ash (Z) will prevail. V. M. Yershov should have checked that on the Kizelov basin coals. This conclusion of ours should be kept in mind because of its great exploration and industrial significance.

ISSUE No. 1 OF GEOLOGY AND GEOPHYSICS
1960
Published by the Siberian Section AN U. S. S. R.[2]

The first issue of a new magazine, "Geology and Geophysics", an organ of the Siberian Section, Academy of Sciences, U. S. S. R., has appeared. It is a monthly publication

[1]Ob osobennostyakh kontsentratsii germaniya v
ennykh uglyakh (po povodu retsenzii V. M. Yer-
a).

[2]O zhurnale "Geologiya i Geofizika" no. 1, 1960, Izdatel'stvo sibirskogo otdeleniya Akad. Nauk SSSR.

(Academician A. A. Trofimok, Editor) denoted to the comprehensive discussion of the problem of geology and geophysics of Siberia.

The editorial, "Science in the Service of the Seven Year Plan", is followed by an article by Academician V. S. Sobolev on a new hypothesis of the origin of diamonds. Corresponding Member AS U. S. S. R. Yu. A. Kuznetsov presents an original review of the history of igneous activity in the Altay-Sayan fold province, in which he stresses the role of granitoid intrusions. N. N. Amshinskiy discusses a new method of determining the depth of truncation of the Altay granite intrusions on the basis of peculiar regularities in the distribution of their impurities, which he has discovered. A novel view of the platform boundaries, as exemplified by the Siberian Platform is presented by Corresponding Member AS U. S. S. R. Yu. A. Kosygin and I. V. Luchitskiy, D. Geol. and Min. Sc.

Corresponding Members AS U. S. S. R. V. N. Saks and Z. Z. Ronika came out with a summary of data extant on the development reliefs in Siberia, in Mesozoic time.

An article by N. A. Florensov, D. Geol. and Min. Sc., proposes to recognize a discrete Mongolo-Baykal neotectonic seismic province; It also offers, on the basis of original reasoning, a new evaluation of Trans-Baykalian seismicity, which is greater than has been assumed before.

In the geophysical section, articles by A. A. Treskov, V. N. Bichevina, and V. A. Larinov propose new geophysical methods of rectilinear epicentrals, present two methods for determination of the thickness of the Earth's crust, and present the derivation of analytic expressions for Za in the vertical plane, along with its application in evaluating the depth of occurrence of magnetic bodies.

In the section on short communication, articles by N. V. Arnautov, L. D. Shipilov, and A. N. Dudarev describe a new method of rapid spectroscopic determination of yttrium in coal ash; they also summarize data on magnetic properties of rocks in the Altay-Sayan province.

The last pages contain reviews of the publications in "Vastnik Zapadno-Sibirskogo i Novsibirskogo Geologicheskikh Upravleniy" (Announcements of the West Siberian and Novosibirsk Geological Administrations) for 1957-1959, and a report on work of the Tectonic College at the Institute of Geology and Geophysics, Siberian Section, AS U. S. S. R.

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